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MONITORING SYSTEM CONCEPTUAL DESIGN (General
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MODULAR BIOWASTE MONITORING SYSTEM

CONCEPTUAL DESIGN

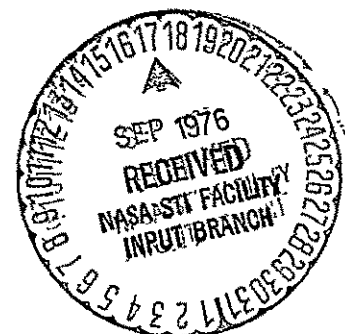
REPORT

CONTRACT NAS9-13748

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

GENERAL  ELECTRIC

GE Report No. 74SD4254
October 1974

MODULAR BIOWASTE MONITORING SYSTEM
CONCEPTUAL DESIGN
REPORT

Contract NAS9-13748

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

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FOREWORD

This report summarizes results of the Modular Biowaste Monitoring System conceptual design study task performed under contract NAS9-13748. NASA technical direction was provided by Mr. R. Sauer, Contract Technical Monitor, and Mr. B. Westover.

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MODULAR BIOWASTE MONITORING SYSTEM
CONCEPTUAL DESIGN STUDY REPORT

1.0 SUMMARY

The objective of the conceptual design study is to define requirements and generate a conceptual design for a Modular Biowaste Monitoring System (BMS) for specifically supporting SHUTTLE life science experimental and diagnostic programs. Table 1-1 lists the general performance requirements for the system. These requirements were expanded, with the assistance of the NASA Technical Monitor, into a detail performance requirements specification.

Table 1-2 summarizes results of the conceptual design study. As noted, the modular concept as applied to the BMS is feasible and will permit scaling the system capability to fit the need for a specific SHUTTLE mission. Two independent baseline subsystems are recommended, a urine S/S for urine collection and volume measurement and a feces S/S for feces collection and mass measurement. These baseline configurations presume that, as a minimum, volume or mass measurement will be required to complement the urine and feces collection capability of the system. Eight other modules are proposed for extending the baseline capability to meet the full performance requirement of the BMS. These modules are for urine analysis and for urine and feces sampling and storage. These add-on modules, then, provide the necessary operating flexibility for meeting the anticipated variable experimental and diagnostic requirements of the SHUTTLE program. Each add-on module include structural support elements with provision for mating with corresponding interface points in each baseline S/S assembly. However, each possible baseline S/S and add-on module combination will require a specifically tailored interconnect cabling and plumbing assembly.

Table 1-1 Modular Biowaste Monitoring System
General Performance Requirements

- (a) The modular system shall provide for the collection and automatic sampling and storage of urine and feces.
- (b) The modular system shall automatically measure urine volume and feces mass in real time.
- (c) The modular system shall include an automatic capability for limited (Na^+ , K^+ , Ca^{++} , Cl^- and TBD ions and pH) real time chemical analysis of individual micturitions.
- (d) The modular system shall provide for multipersonal use, both male and female.
- (e) The modular system shall be automated to minimize spacecraft crew time requirements.
- (f) The system shall be modular in configuration so that functional capability can be easily increased or decreased depending on the life science requirements for a particular shuttle mission.

TABLE 1-2 SUMMARY, CONCEPTUAL DESIGN STUDY RESULTS

MODULAR APPROACH FOR BMS PRACTICAL

- 2 INDEPENDENT BASELINE S/S's
- 8 ADD-ON MODULES (URINE ANALYSIS, URINE AND FECES SAMPLING AND STORAGE AND FLUSH FLUID)
- TAILORED PLUMING/WIRING INTERCONNECT HARDWARE

POWER/WEIGHT MAY BE EXCESSIVE, PARTICULARLY FOR TOTAL BMS CAPABILITY

- REVIEW SAMPLING REQUIREMENTS
 - QUANTITY/TYPE/SIZE
 - STORAGE VOLUME/TEMPERATURE
 - FLUSH FLUIDS (CROSS-CONTAMINATION)

BMS/WCS INTEGRATION PRACTICAL

- WCS CAN BE COMPLETELY INTEGRATED INTO BMS
- POTENTIAL PROBLEM AREAS, REVIEW/DETERMINE
 - EQUIPMENT LOCATION
 - POWER AVAILABILITY
 - FLUID DISPOSAL

Based on estimates for the total capability of the BMS and maximum mission conditions (6 men, 30 days), total weight and power (307 lbs. plus 445 lbs. of expendables and 565 watts peak) may be incompatible with SHUTTLE capability. Since the bulk of the weight and power required are to satisfy sampling requirements, a review of sample size, quantity and type, storage temperature and need for refrigerated storage and cross-contamination requirements is recommended.

Integration of the Shuttle Waste Collection Systems (WCS) with the BMS was investigated. As presently defined, the WCS is readily integrated into the BMS. Equipment commonality is excellent, however, a possible equipment installation problem exists for an integrated BMS/WCS assembly.

2.0 BACKGROUND

The acquisition of crew biomedical data has been an important task on all manned space missions from Project Mercury through the just completed Skylab Program. The monitoring of biowastes from the crew is a valuable part of this activity. On early missions, emphasis was placed on the collection and return of biowaste samples for post mission analysis; on later missions such as Skylab, equipment for inflight measurement of urine/feces volume or mass was also added. For SHUTTLE, real-time measurements and an increase in automation will be required. Sampling on selected missions will also be required.

Figure 2-1 illustrates a projected hardware development plan for biowaste monitoring on SHUTTLE. The plan builds on the results of past and current development activity to accomplish the hardware development of a Modular Biowaste Monitoring System to support SHUTTLE life science activities. Contract NAS9-13748 is a first step in implementing this plan.

3.0 TECHNICAL

3.1 System Requirements

Table 1-1 lists the general performance requirements for the Modular Biowaste Monitoring System (BMS) as specified in the contract (NAS9-13748) work statement. These basic requirements were expanded (with the assistance of the NASA Technical Monitor) into a detail performance requirements specification. This specification is included in this report as Appendix 4.1 and summarized in Table 2-1.

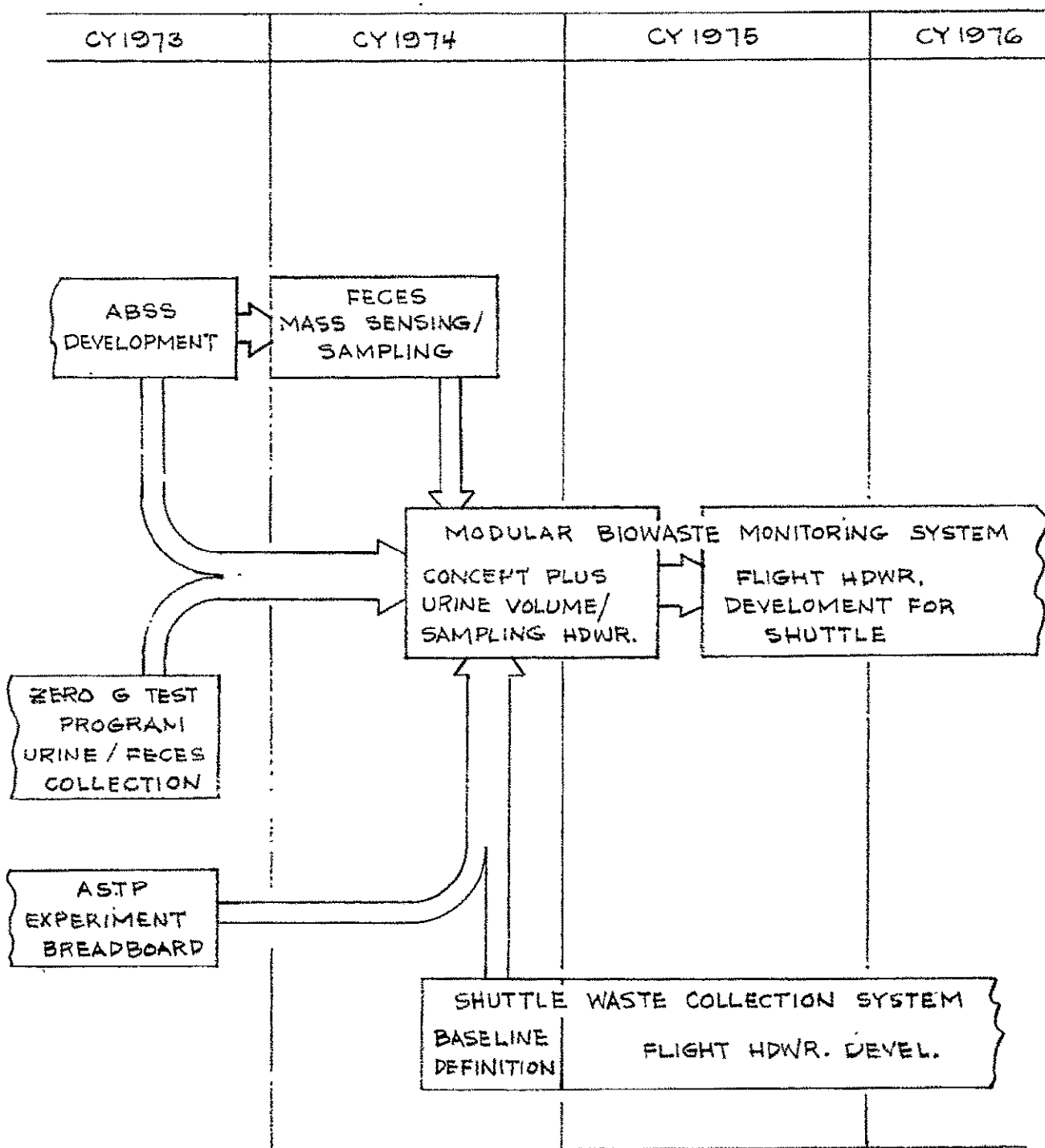


Figure 2-1 Modular Biowaste Monitoring System Development Plan

TABLE 2-1 BMS BASIC PERFORMANCE REQUIREMENTS

COLLECTION

- URINE AND FECES USING TRANSPORT AIR FLOW

MEASUREMENT (REAL TIME)

- URINE (INDIVIDUAL MICTURITIONS)
VOLUME: ERROR, + 2% OF ACTUAL
CHEMICAL ANALYSIS: IONS AND pH
- FECES (INDIVIDUAL DEFECATIONS)
MASS: ERROR, \pm 2% OF ACTUAL

SAMPLING

- URINE
2 \pm 1 ml MICRO-ORGANISM SAMPLE
5 \pm 1 ml CHEMICAL SAMPLE
24-HOUR POOL SAMPLE (10% OF EACH
MICTURITION; VOLUME ERROR \pm 2%)
- FECES
20% (NOMINAL) OF TOTAL DEFECATION
- CROSS-CONTAMINATION 0.5 GMS

STORAGE

- SAMPLES
REFRIGERATED (4°, -20° AND -70°C)
CHEMICAL STABILIZATION

DISPOSAL

- DUMP EXCESS URINE TO SHUTTLE WASTE
LIQUID STORAGE TANKS (WITH BIOCIDES ADDED)
- RETAIN EXCESS FECES (AND TISSUE WIPE);
VACUUM DRY MICROORGANISM CONTROL

OPERATIONAL

- MALE AND FEMALE SUBJECTS (6 TOTAL)
- AUTOMATIC
- MODULAR TO MEET SPECIFIC MISSION REQUIREMENTS
- POWER (28 VDC; 115, 200 V, 400 HZ AC)
- MALFUNCTION INDICATION
- MEASUREMENT DATA TO TLM ONLY
- USEFUL LIFE WITH MAINTENANCE: 100 MISSIONS
- SHUTTLE FLIGHT ENVIRONMENTS
- INTEGRATE WITH SHUTTLE WCS

3.2 Functional Elements

Figure 3-1 shows the functional elements required to implement the system performance requirements. Note that three categories of functions are shown. These are urine related and feces related functions and those functions common to both urine and feces biowastes. Not shown is a possible fourth category of elements needed to interface the system with the SHUTTLE spacecraft. Each of the elements in these categories is discussed in the following sections. Wherever possible, the application of hardware concepts and operating procedures proven on past related programs is emphasized.

3.2.1 Urine Related Elements

3.2.1.1 Collection

The function of the urine collection element is to collect and retain expelled urine from male or female users and to direct this urine into the phase separator. A urinal and flex hose make up the basic hardware for this function. From a system viewpoint, transport airflow requirements, sanitation and cross-contamination are the key considerations.

Two basic types of urinal designs have been investigated in previous programs. These two basic urinals are (1) a contact (fitted) type, and (2) a non-contact (open trough) type. The fitted urinal is somewhat more complicated in that a positioning capability must be included, whereas the open trough design can be fixed in place. Both types have desirable features although for the Modular Biowaste Monitoring System (BMS) application, the fitted contact urinal is an obvious first choice, Table 3-1. The fitted urinal provides the highest degree of positive containment of the urine resulting in a high degree of user confidence for female users. In addition, this

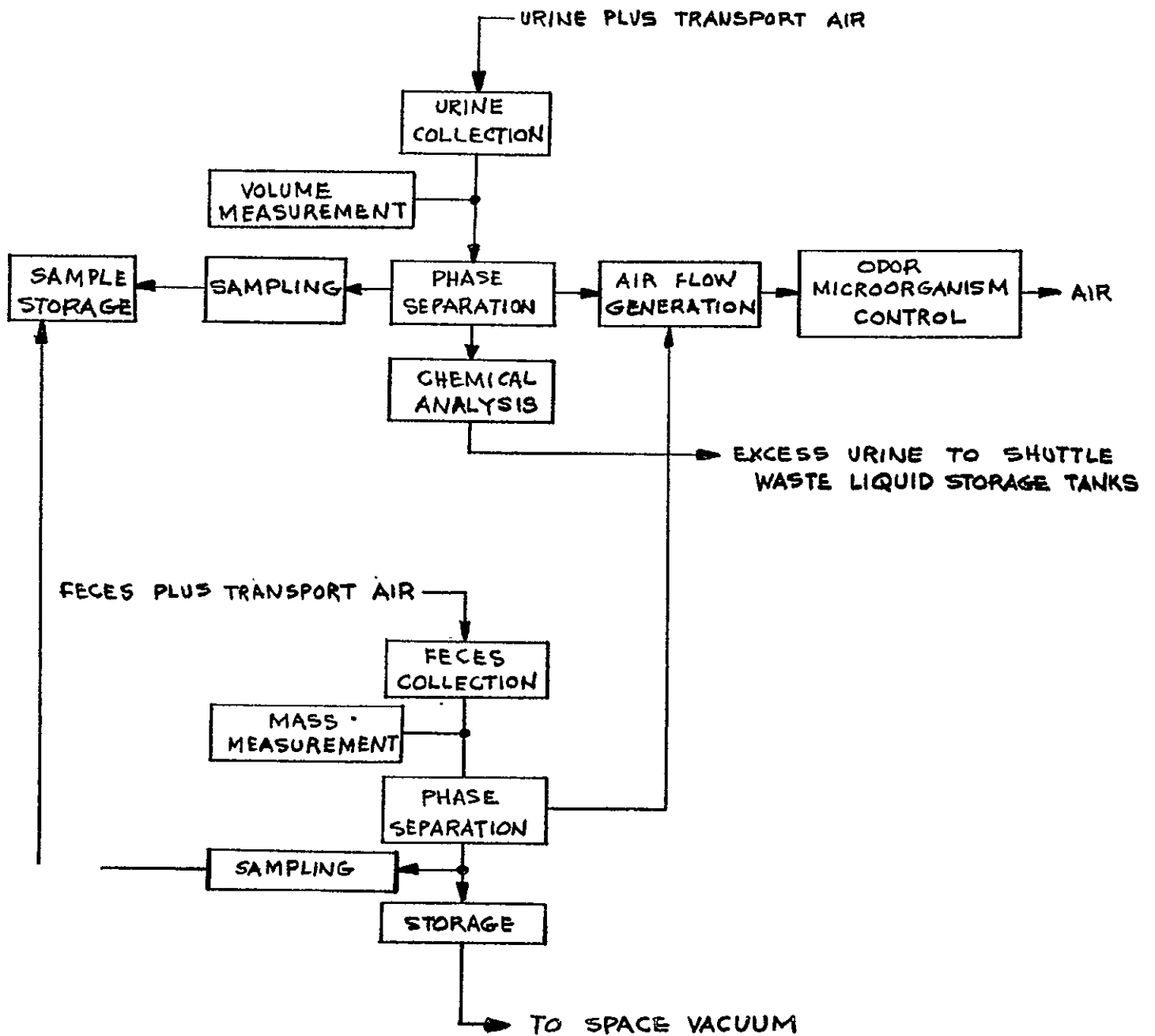


Figure 3-1 Functional Block Diagram, Modular Biowaste Monitoring System

Table 3-1 Urinal Concept Comparison Summary

Item	Contact "Fitted" Type Urinal	"Trough" Type Urinal
Air flow requirement	8-10 CFM	15 CFM ⁽¹⁾
Containment	Best ⁽²⁾	--
User confidence	Best ⁽³⁾	--
User cross-contamination	(5)	Best ⁽⁴⁾
Sample cross-contamination	Water flush required for both types	
Location	Positionably adjustable	Fixed
Stand-up use	Yes	No
Design simplicity	--	Best
State of development	Both types zero g A/C tested	

- (1) For near proximity to user; transport air flow requirements 2X to 3X for user/urinal separation of several inches.
- (2) For given urinal opening.
- (3) Based on user comments.
- (4) Neglecting probable accidental contact which becomes highly probable as user/urinal separation is reduced to near proximity.
- (5) Provide personalized reusable or disposable interface protection device for positive protection.

urinal permits "stand-up" use with a minimum of disrobing.

Zero gravity tests including 8 males and 12 females indicated that the fitted urinal was highly satisfactory for both male and female users, see GE Report No. 74SD4221. The residual urine removal action of the fitted urinal was so effective for the females that vaginal wipes were not required following micturition. The tests also established that the urinal was fully compatible for both the male and female users, and provided positive urine containment and effective transport for all users at a 8 CFM air flow and even at zero air flow, no urine escaped the urinal. In addition, the positionability and tension maintaining design also permitted movement of the user (females) while still providing positive urine containment. This latter feature, which positions the urinal against the female user with a 7 to 10 lb. spring force, results in the labia being opened thus assuring a more integrated, direct flow of urine. The opening of the labia combined with the air flow entering around the perimeter of the urinal at high velocity "pinches off" any urinal drops and carries away the normal residual urine from the labia/vulva area.

Protection of users from microbiological cross-contamination is an important consideration. The potential for cross-contamination is present in any type of urinal either "fitted" or "open trough" type. For example, accidental or procedural contact with a urinal of the "open trough" type is a likely occurrence since the devices, due to a variety of requirements, are by design positioned in close proximity to the genital and perineal area of the user. Further complicating this problem for the "open trough" type urinal, the further away from the user the urinal is positioned the larger the urinal opening must be and the higher the air flow must be to assure adequate urine collection. The best solution to solve the potential cross-contamination problem for either a fitted or open trough urinal

is to provide positive cross-contamination protection. Either a personalized or disposable interface can be used. Disposable interfaces of plastic or paper can be developed but require significant storage volume in the spacecraft before and after use. Thus personalized individual urinal interface caps which are placed over the urinal opening (snap fit) and removed after micturition are preferred.

In summary, the contact (fitted urinal with personalized interface cap) is recommended as the preferred approach for the Modular Biowaste Monitoring System. Figure 3-2 shows an example of a fitted urinal.

3.2.1.2 Phase Separation

The basic functions of the phase separator are to remove the urine from the transport airstream and to provide temporary storage for each individual micturition prior to sampling. This latter is necessary to assure that the sample is representative of the entire micturition. A secondary function is to filter out urine particulates (hair and skin particles) which could cause downstream failure of valves and/or plumbing. Also, as discussed in section 3.2.1.3, the phase separator may be combined with other components to provide a measure of urine volume.

Both static and dynamic type separators have been investigated for zero g fluid/air separation. Static type using hydrophobic/hydrophilic material combinations (tried but rejected for Skylab) cannot be demonstrated in one "g" and urine contamination causes degradation of the surface properties. Air flow induced vortex type separators require a high air flow pressure drop and are also difficult to demonstrate under one "g" conditions. Further, since the resulting liquid vortex configuration is relatively unpredictable as far as level detection is concerned, urine pump cavitation, i.e. pumping of a urine/air mixture, is difficult to prevent during final evacuation of the urine from the phase separator.

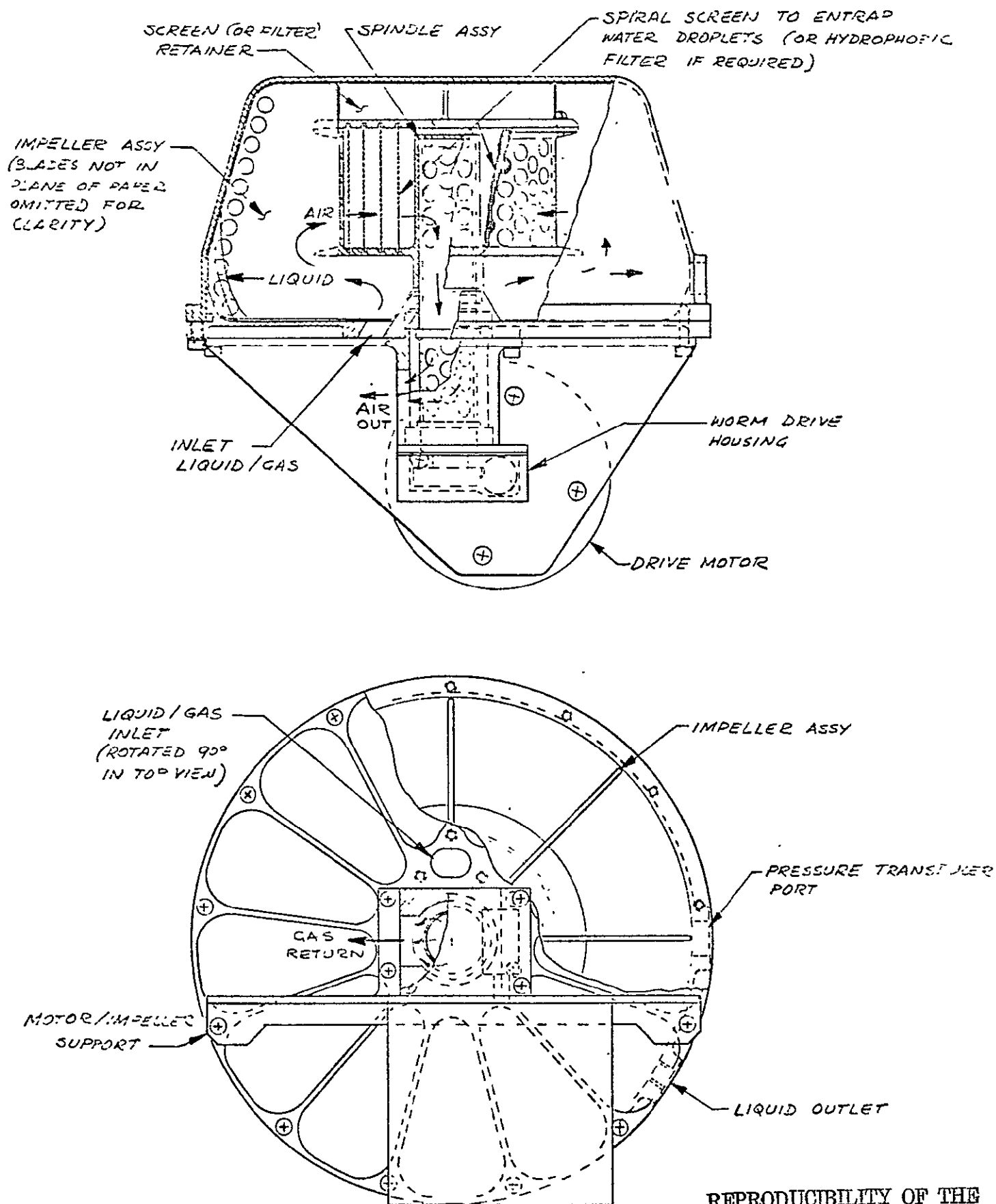


Figure 3-2 Fitted Urinal Assembly

Dynamic types use either a rotating impellor in a fixed external housing or a rotating housing to generate a fluid vortex (about the inner periphery of the housing) by centrifugal action. In the case of the rotating impellor type, liquid may be removed from the phase separator via a port in the fixed housing; the rotating housing type uses an internal fixed probe immersed in the vortex for removing fluid. A dynamic type, whether a driven impellor or driven housing type, can be positively demonstrated under one "g" conditions and because of the fixed geometry of the vortex, pump cavitation can easily be prevented. The driven housing type used on Skylab is inherently more complex mechanically and more costly to produce. The rotating impellor type has been used by GE for a number of urine collection, volume measurement and sampling hardware systems and has been qualified to ASTP mission flight requirements. The rotating impellor type, see figure 3-3, also exhibits a minimal residual, an important consideration for a urine sampling function. In addition, the rotating impellor type may be readily instrumented and controlled to provide urine volume measurement (as discussed in section 3.2.1.3). Thus, the rotating impellor type phase separator was selected as the preferred approach for the Modular Biowaste Monitoring System application. Table 3-2 summarizes a comparison of the two phase separator concepts.

3.2.1.3 Volume Measurement

Volume measurement refers to the automatic real time determination of the total volume of each individual micturition. The volume measurement equipment is also required to control sampling, i.e. the volume of fluid injected into individual chemical and 24-hour pool sample containers. Volume reduction of the 24-hour pool is a third type requirement. For the BMS application, volume may be determined by monitoring liquid flow into or out of the phase separator and integrating this flow



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Figure 3-3 Impeller Type Phase Separator Assembly

LIQUID/GAS SEPARATOR

John L. Pionard: 4-25-78

TABLE 3-2 Phase Separator Concept Comparison Summary

Item	Rotating Impellor Type	Rotating Housing Type
Design Simplicity	Best	--
Effectiveness	(1)	(1)
Liquid residual	Least	--
Liquid carryover barrier	Yes	Yes
Compatible with volume measurement	Best (2)	--
State of development	Qualified for ASTP	Used on Sky ¹⁻²
Weight, volume, power	(3)	(3)

(1) Equal for given diameter, rotational speed and transport air flow rate.

(2) Difficult to sense internal fluid conditions when housing rotates.

(3) Roughly comparable for a given requirement.

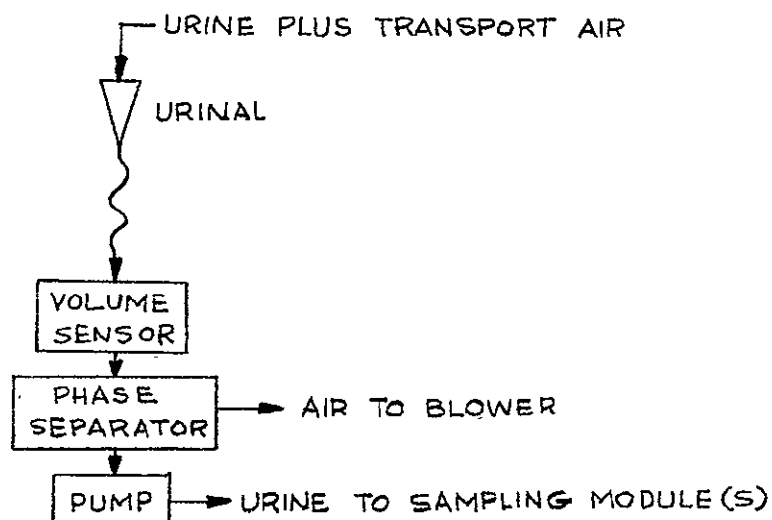
to determine total volume or by measuring the total liquid volume within the phase separator at the completion of micturition. Each of these three volume measurement approaches is discussed in detail below.

3.2.1.3.1 Measurement Upstream of Phase Separator

Figure 3-4 shows the urine volume sensor located upstream of the phase separator. In this position, the volume sensor must be able to discriminate the urine portion of the urine/transport air mixture entering the urinal. For a 10 CFM transport airflow and at the maximum urine input condition (25 ml/sec.), the liquid content of the two phase mixture is only 0.53%. Two possible candidate sensors have been identified for measuring urine volume under this flow condition:

- (1) A thermal type flow sensor as developed by Geoscience Ltd. under NASA contracts NAS9-11612 and NAS9-13461; and
- (2) An adaptation of the feces mass measurement concept currently being developed by GE under NASA contract NAS1-11443, Mod. 5S.

The Geoscience Ltd. thermal flow sensor consists essentially of two parts, the flow tube sensing element and the supporting electronics. In operation, a constant amount of thermal energy is added to the thermally isolated (from ambient) flow tube. Urine in the air/urine mixture flowing thru the tube extracts heat from the tube; the resulting change in tube wall (longitudinal) temperature gradient is a function of urine flow rate (comparatively the heat extracted by the air portion of the urine/air mixture is negligible). This transient temperature gradient (equivalent to transient urine flow rate) is measured by a thermopile. The output of the thermopile is then inverted and integrated to give total urine volume. Development hardware



FUNCTION	MAXIMUM ERROR ⁽¹⁾	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm 2\%$	$\pm 2\%$ ⁽²⁾
SAMPLE VOLUME CONTROL CHEMICAL	$\pm 20\%$	$\pm 20\%$ ⁽³⁾
10% 24-HOUR POOL	$\pm 2\%$	N/A ⁽⁴⁾

(1) INDIVIDUAL MICTURITION.

(2) BASED ON GEOSCIENCE LTD. THERMAL FLOW SENSOR BREADBOARD DATA.

(3) CONTROLLED BY CONTAINER GEOMETRY.

(4) NO DOWNSTREAM CONTROL POSSIBLE USING UPSTREAM SENSOR.

Figure 3-4 Urine Volume Measurement, Sensor Located Upstream of Phase Separator

and principles of operation are described and discussed in detail in Geoscience Ltd. reports GLR 113 and 124.

The GE feces mass measurement device uses the "slinger assembly", a part of the GE Dry-John type feces waste collection concept. The impact of solids (or liquids) with the slinger results in a transfer of energy from the slinger to the solid (or liquid) particles. By operating the slinger at a constant rotational velocity, the incremental energy input to the slinger motor is proportional to the incremental solid (or liquid) mass. Total mass is then obtained by integration of these incremental power inputs. For measurement of urine volume only, the slinger portion would be scaled down to match the low (comparatively) micturition flow rate and optimized for liquid flow only.

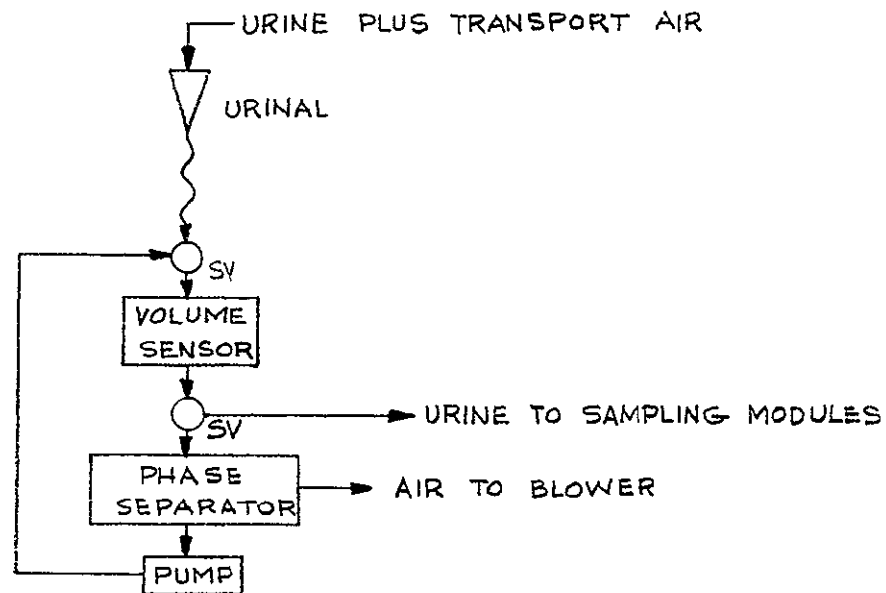
The Geoscience Ltd. thermal flow sensor concept has been developed to the engineering prototype stage. Geoscience Ltd. Report GLM-137, Appendix 4.2 wherein, discusses design modifications for the SHUTTLE application. Depending on other elements in the Modular Biowaste Monitoring System, the relatively high air flow pressure drop thru the flow tube sensing element may be limiting. The GE mass measurement device is currently in the breadboard development stage, thus a meaningful comparison with the thermal flow sensor is impossible. However, based on effort to date, the GE device would appear to be somewhat smaller in volume but also somewhat heavier for the same measurement performance.

The Geoscience Ltd. thermal flow sensor and (probably) the GE mass measurement device have the potential for measuring total urine volume within the specified $\pm 2\%$. However, in the upstream location, the volume sensor cannot be used to control the fluid volume directed into individual sample containers. The phase separator, which must be

present to remove transport air before sampling, in effect isolates the upstream volume sensor from performing other system functions.

Figure 3-5 eliminates the volume sensor isolation by recirculating the urine flow from the phase separator back thru the volume sensor. This permits the volume sensor to control the fluid volume directed to each individual sample container. Operationally, urine is stored in the phase separator until micturition is complete. The resulting urine volume value is stored electronically and the 10% input to the 24-hour pool sample container computed. The urine is then pumped out of the phase separator and back thru the volume sensor and out to the sample containers (with excess to dump). For Figure 3-5, an important point to note is that the error analysis assumes that the volume sensor error will not change for the liquid only flow condition as compared to the air/liquid flow condition. This assumption is of doubtful validity and consequently the estimated 24-hour pool volume error may be larger than shown in Figure 3-5.

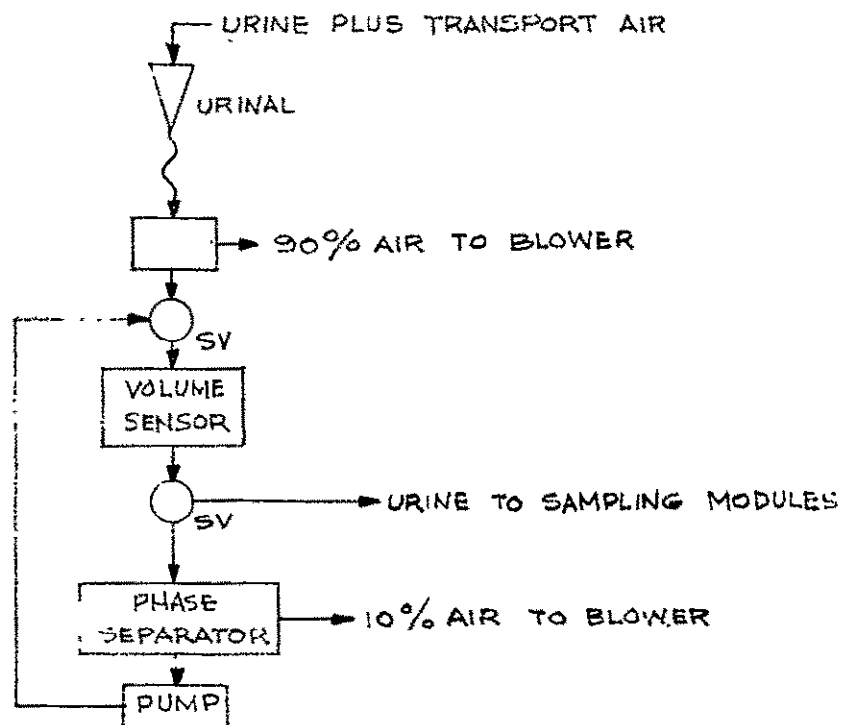
In summary, the thermal flow sensor (or equivalent device) is ideally suited to those applications, e.g. ASTP, where the urine and transport air mixture may be vented directly to space vacuum (urinal and flow sensor only required) or applications where close control of urine sample volume is not required, i.e. sample container geometry is used to control sample volume. This latter is probably satisfactory for individual urine chemical samples but cannot be used for 24-hour pool sampling as required for the BMS. 24-hour pool sampling can be accomplished (for Figure 3-5 concept) by recirculating the urine from the phase separator back thru the volume sensor and out to the phase separator. Figure 3-6 illustrates a second alternate wherein the airflow thru the thermal flow sensor can be greatly reduced to minimize blower power. A third alternate involves the use of a redundant volume sensor down-



FUNCTION	MAXIMUM ERROR(1)	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm 2\%$	$\pm 2\%$ (2)
SAMPLE VOLUME CHEMICAL	$\pm 20\%$	$\pm 20\%$ (3)
10% 24-HOUR POOL	$\pm 2\%$	$\pm 2.8\%$ (4)

- (1) INDIVIDUAL MICTURITION.
- (2) BASED ON GEOSCIENCE LTD. THERMAL FLOW SENSOR BREADBOARD DATA.
- (3) CONTROLLED BY CONTAINER GEOMETRY.
- (4) ASSUMES $\pm 2\%$ SENSOR ERROR FOR BOTH FLOW MODES AND FLUID FLOW RANGE OF 5 TO 100 ml FOR SAMPLE.

Figure 3-5 Urine Volume Measurement, Upstream Sensor Location With Recirculate Urine Flow



FUNCTION	MAXIMUM ERROR ⁽¹⁾	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm 2\%$	$\pm 2\%$ ⁽²⁾
SAMPLE VOLUME CONTROL CHEMICAL (5 ml)	$\pm 20\%$	$\pm 20\%$ ⁽³⁾
10% 24-HOUR POOL	$\pm 2\%$	$\pm 2.8\%$ ⁽⁴⁾

- (1) INDIVIDUAL MICTURITION.
- (2) BASED ON GEOSCIENCE LTD. THERMAL SENSOR BREADBOARD DATA.
- (3) CONTROLLED BY CONTAINER GEOMETRY.
- (4) ASSUMES $\pm 2\%$ SENSOR ERROR FOR BOTH FLOW MODES AND FLUID FLOW RANGE OF 5 TO 100 ml FOR SAMPLE.

Figure 3-b Urine volume Measurement, Upstream Sensor Location
With Recirculate Urine Flow and Reduced Air Flow

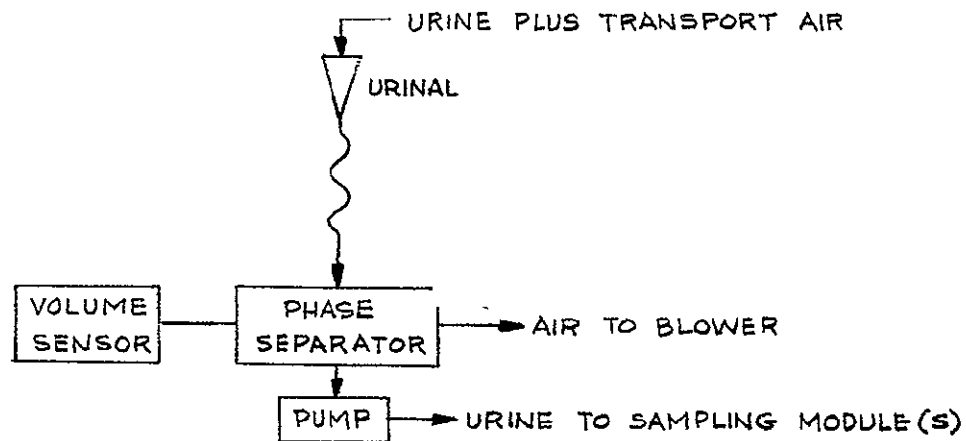
stream of the phase separator. However, as noted in section 3.2.1.3.3, this downstream sensor can provide directly both total urine volume and sampling control.

3.2.1.3.2 Measurement Combined With Phase Separation

Figure 3-7 illustrates the basic concept. In this measurement approach, the phase separator is combined with a volume sensing device. As noted previously, urine is temporarily stored in the phase separator in the form of a rotating liquid vortex. If the phase separator is operated at a constant rotational velocity, the "depth" of the urine vortex will be proportional to the total urine volume. The volume sensor, Figure 3-7, senses this vortex depth and computes the corresponding liquid volume.

A pressure transducer located on the periphery of the phase separator stationary housing may be used as a non-intrusive volume sensor. An ultrasonic type device is an alternate candidate. The basic concept was demonstrated as part of the effort under contract NAS9-13519, ASTP Fluid Transfer Measurement Experiment. Details of this effort are reported in GE report No. 74SD4215. Test results show urine volume measurement error within $\pm 2.2\%$ (2 sigma value).

In addition to measurement of total micturition volume, the above approach can be used to control the volume of urine directed into individual sample containers at each micturition. This is accomplished by monitoring the net outflow of urine (i.e. change in vortex depth) and when the desired difference is reached, stop urine flow to the sample container. The amount dispensed could be either a fixed value or a percent of the total. Fixed volume chemical samples will exhibit relatively large volume errors. Assuming a measurement threshold sensitivity of ± 1 ml, the resulting volume error for a 5 ml chemical sample is $\pm 20\%$. Chemical sample volume control using container geometry is the preferred alternate.



FUNCTION	MAXIMUM ERROR ⁽¹⁾	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm 2\%$	$\pm 2.2\%$ ⁽²⁾
SAMPLE VOLUME CONTROL CHEMICAL	$\pm 20\%$	$\pm 20\%$ ⁽³⁾
10% 24-HOUR POOL	$\pm 2.0\%$	$\pm 3.1\%$ ⁽⁴⁾

- (1) INDIVIDUAL MICTURITION.
- (2) GE PHASE SEPARATOR VORTEX PRESSURE (CALIBRATED CENTRIFUGE) TEST DATA (2 SIGMA VALUE).
- (3) CONTROLLED BY CONTAINER GEOMETRY.
- (4) ASSUMES $\pm 2.2\%$ ERROR FOR BOTH MEASUREMENT MODES, i.e. 50 TO 1000 ml AND 5 TO 100 ml RANGES).

- VOLUME SENSOR PROVIDES PHASE SEPARATOR MALFUNCTION ALARM (REQUIRED FOR WCS)

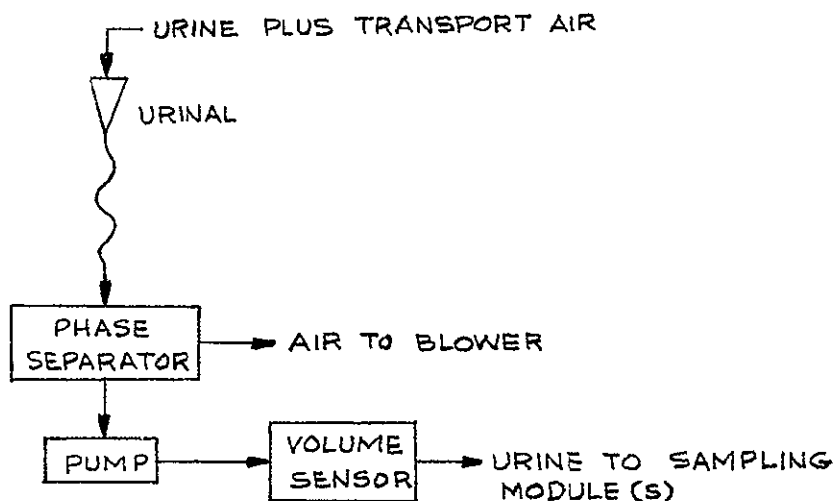
Figure 3-7 Urine Volume Measurement, Sensor Located at Phase Separator

In summary, a sensor which functions by measuring the volume in the phase separator can measure both total micturition volume and control the volume of urine directed to individual urine sample containers. Measurement of total micturition volume with a two sigma error of less than $\pm 2.2\%$ has been demonstrated. A 24-hour pool volume sensor error of less than about $\pm 3.1\%$ is possible. Achieving a 24-hour pool volume sensor error of $\pm 2.0\%$ may be possible by close control of component tolerances.

3.2.1.3.3 Measurement Downstream of Phase Separator

Figure 3-8 shows the volume sensor in the downstream location. At this point in the system, only liquid flow is encountered. This latter flow condition increases the types of volume sensors which can be used (as compared to the upstream volume sensor location, see section 3.2.1.3.1). Possible sensor candidates capable of measuring total urine volume with an error of less than $\pm 2\%$ include turbine, ultrasonic (doppler effect) and thermal type flow rate sensors and positive displacement volume type sensors. However, as indicated on Figure 3-8, the downstream (of the phase separator) location of the volume sensor does not permit volume control for the 24-hour pool sample since the 24-hour pool sample input is 10% of the micturition volume. Thus the volume to the 24-hour pool sample container cannot be determined until all of the urine has passed thru the volume sensor. Recirculating urine back to the phase separator or adding a second sensor in series will not alleviate this problem.

Adding an automatic flow proportioning capability to the downstream volume sensor will permit volume control for the 24-hour pool sample. The ABSS volume measurement concept has this capability and is described in detail in GE report No. 74SD4208, Part I. Briefly, a dual chamber reciprocating piston device is used as a positive displacement volume sensor. The two chambers are sized in a 90% to 10% volume ratio; the two pistons are coupled to a common shaft for coordinated movement.



FUNCTION	MAXIMUM ERROR ⁽¹⁾	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm 2\%$	$\pm 2\%$ ⁽²⁾
SAMPLE VOLUME CONTROL	$\pm 20\%$	$\pm 20\%$ ⁽³⁾
CHEMICAL	$\pm 2\%$	N/A ⁽⁴⁾
10% 24-HOUR POOL		

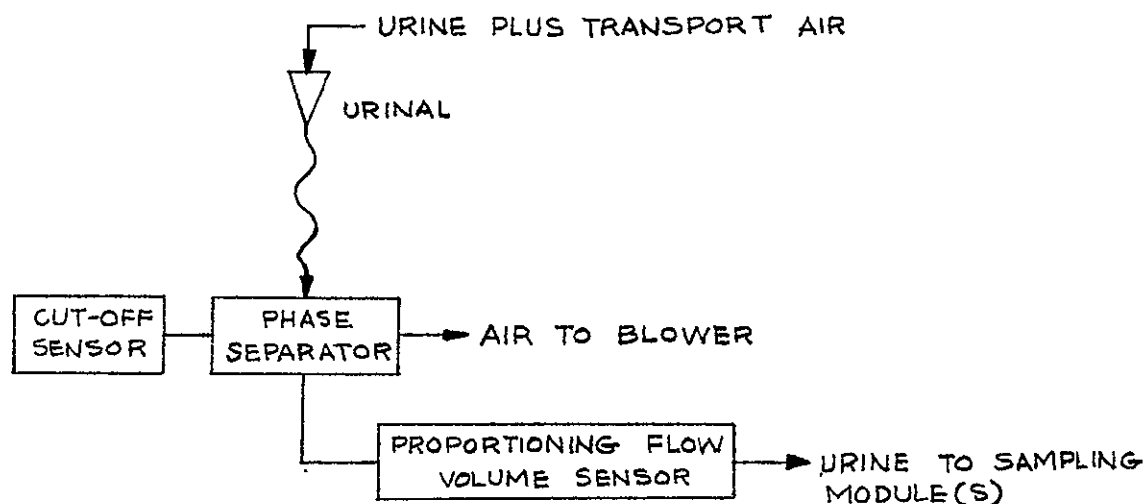
- (1) INDIVIDUAL MICTURITION.
- (2) ASSUMED BASED ON COMMERCIAL HARDWARE CAPABILITY.
- (3) CONTROLLED BY CONTAINER GEOMETRY.
- (4) NEED MICTURITION VOLUME IN ORDER TO DETERMINE 10% POOL VOLUME:

Figure 3-8 Urine Volume Measurement, Sensor Located Downstream of Phase Separator

A position sensor monitors shaft position (and thus urine volume in the two chambers). The two chambers are filled by pump pressure; integral return springs are used to discharge the chambers. In operation the two chambers are alternately filled and emptied until the urine volume is reduced to 50 ml in the phase separator. During this process, the content of the 90% chamber is directed to the waste dump outlet and the content of the 10% chamber directed to the 10% 24-hour pool sample container. At the 50 ml point, the total micturition volume is the volume already measured plus 50 ml. Also an additional 5 ml is added to the 10% 24-hour pool sample container to compensate for the 50 ml cut-off. A compensation for system fluid residual can also be added if desired.

Figures 3-9 and 3-10 show the concept block diagram and corresponding performance. All BMS requirements can be met. The discrepancy between actual USCS data and the idealized capability is due to an apparent variable proportionality ratio. Since this ratio is fixed by the size of the two measurement chambers, the apparent variation of $\pm 0.6\%$ (3 sigma value) may be due, at least in part, to test procedure error. Assuming the USCS data is correct, a total 24-hour pool volume 2 sigma error of $\pm 0.5\%$ can be expected (avg. size micturition) which is significantly less than the $\pm 2\%$ allowed.

In summary, a positive displacement sensor in combination with a flow proportioning capability can meet the BMS volume measurement and sample volume accuracy. The accuracy of this concept has been demonstrated as part of the ABSS program. Six week life tests (using urine) were also performed on an earlier system (USCS) with no apparent microorganism growth or other problem. It should also be noted that 24-hour pool sampling cannot be accomplished using a downstream located volume sensor without a corresponding proportioning flow capability. This is due to the fact that the total micturition volume is unknown while sampling is occurring.



FUNCTION	MAXIMUM ERROR ⁽¹⁾	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm .2\%$	$\pm 1.6\%$ ⁽²⁾
SAMPLE VOLUME CONTROL	$\pm 20\%$	$\pm 5\%$ ⁽³⁾
CHEMICAL	$\pm -2\%$	$\pm 0.5\%$ ⁽⁴⁾
10% 24-HOUR POOL		

(1) INDIVIDUAL MICTURITION.

(2) ABSS TEST DATA (2 SIGMA VALUE).

(3) $5 \text{ ml} \pm .25 \text{ ml} = 5 \text{ ml} \pm 5\%$ IF CONTROLLED BY SENSOR; $\pm 20\%$ IF CONTROLLED BY CONTAINER GEOMETRY.

(4) BASED ON USCS PROPORTIONING FLOW VOLUME SENSOR TEST DATA AND AVERAGE SIZE MICTURITION.

Figure 3-9 Urine Volume Measurement, Sensor Integrated With Flow Proportioning Element

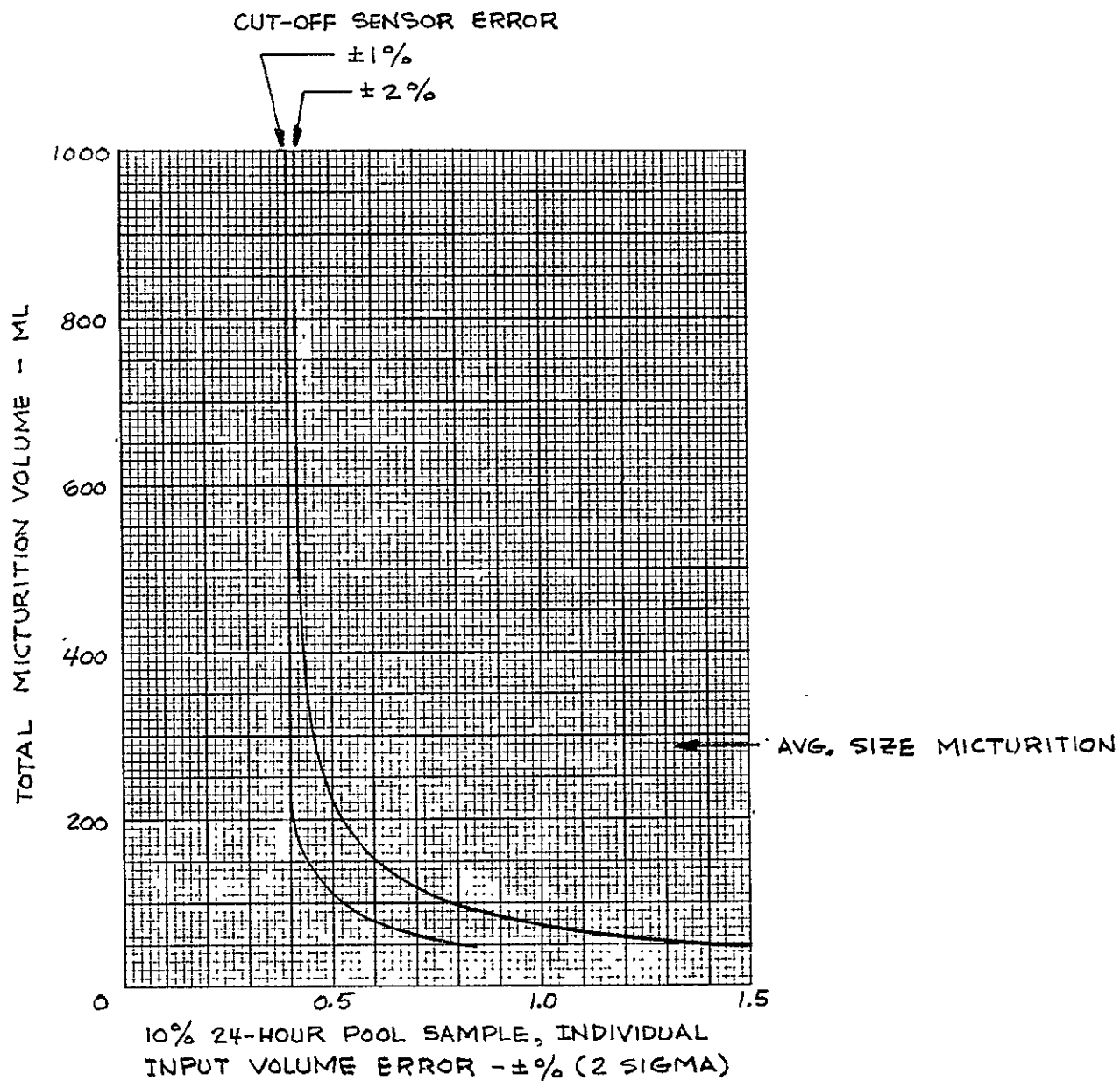


Figure 3-10 Estimated 24-Hour Pool Sample Volume Error (Based on USCS/ABSS Data)

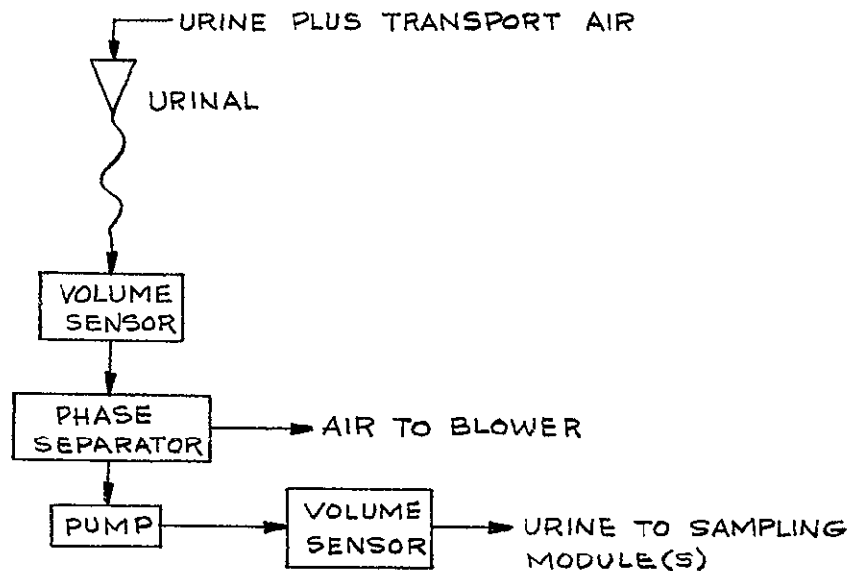
Proportionate sampling alleviates this factor.

3.2.1.3.4 Combination Location

Figure 3-11 shows volume sensors located both up and downstream of the phase separator. Assuming both sensors can measure volume within a $\pm 2\%$ error, overall performance is equivalent to a $\pm 2\%$ volume sensor combined into the phase separator (figure 3-7) or an upstream located sensor with recirculation (figure 3-5 and 3-6). As shown, the added complexity of a second volume sensor does not reduce the 24-hour pool sample volume error to less than the allowable $\pm 2\%$.

3.2.1.3.5 Comparison Summary

As shown in Table 3-3, one of the volume sensor concepts discussed above more than meets the performance requirements of the Modular Biowaste Monitoring System, i.e. the downstream (of the phase separator) located positive displacement volume sensor with built-in automatic proportional flow capability. Performance of this type sensor has been demonstrated as part of the USCS and ABSS programs. This type sensor also has one additional capability not available with the alternate concepts, i.e. the accurate measurement of small urine volumes needed for chemical sampling (5 ml) and for residual volume (1 to 2 ml) and other possible compensation. The ABSS device can, for example, control these small volumes to within 0.25 ml. This type of precision sampling control cannot be accomplished using the alternate volume sensor concepts discussed. Also, this type sensor has the capability for directly providing in-place volume reduction control. This is accomplished by operating the sensor in the reverse mode. Figure 3-12 illustrates a first cut of an improved mechanization of the ABSS sensor design for the BMS application.



FUNCTION	MAXIMUM ERROR ⁽¹⁾	
	REQUIREMENT	ESTIMATED CAPABILITY
VOLUME MEASUREMENT	$\pm 2\%$	$\pm 2\%$ ⁽²⁾
SAMPLE VOLUME CONTROL	$\pm 20\%$	$\pm 20\%$ ⁽³⁾
CHEMICAL	$\pm 2\%$	$\pm 2.8\%$ ⁽⁴⁾
10% 24-HOUR POOL		

- (1) INDIVIDUAL MICTURITION.
- (2) ASSUMED CAPABILITY.
- (3) CONTROLLED BY CONTAINER GEOMETRY.
- (4) ASSUMES $\pm 2\%$ ERROR FOR BOTH SENSORS.

Figure 3-11 Urine Volume Measurement, Upstream/Downstream Location of Sensors

TABLE 3-3 - URINE VOLUME MEASUREMENT

● SUMMARY

VOLUME SENSOR APPROACH	MAXIMUM SENSOR ERROR (1)			WEIGHT LBS.	POWER (PEAK) WATTS	DEVEL. STATUS
	TOTAL VOLUME	CHEMICAL SAMPLE	24-HOUR POOL			
UPSTREAM						
● THERMAL SENSOR WITH URINE FLOW RECIRCULATION	$\pm 2\%$ (2)	$\pm 20\%$	$\pm 2.8\%$ (5)	7.0(7)	59 (7)	CONCEPTUAL
● THERMAL SENSOR WITH URINE FLOW RECIRCULATION AND 10% AIR FLOW	$\pm 2\%$ (2)	$\pm 20\%$	$\pm 2.8\%$ (5)	5.6(8)	49(8)	CONCEPTUAL
AT PHASE SEPARATOR						
● CALIBRATED CENTRIFUGE VOLUME SENSOR	$\pm 2.2\%$ (3)	$\pm 20\%$	$\pm 3.1\%$ (5)	2.1(9)	5(9)	BREADBOARD
DOWNSTREAM						
● POSITIVE DISPLACEMENT PROPORTIONING FLOW VOLUME SENSOR	$\pm 1.6\%$ (4)	$\pm 5\%$	$\pm 0.5\%$ (6)	4.6(10)	14(10)	ENGRG. PROTOTYPE

- (1) INDIVIDUAL MICTURITION.
- (2) ESTIMATED BASED ON GEOSCIENCE LTD. THERMAL SENSOR BREADBOARD TEST DATA.
- (3) CALIBRATED CENTRIFUGE BREADBOARD TEST DATA (2 SIGMA VALUE AT 50 ml).
- (4) ABSS TEST DATA (2 SIGMA VALUE AT 50 ml).
- (5) ESTIMATED
- (6) USCS TEST DATA FOR AVERAGE SIZE MICTURITION.
- (7) FLOW SENSOR, SENSOR ELECTRONICS AND SOLENOID VALVES.
- (8) FLOW SENSOR, SENSOR ELECTRONICS, SOLENOID VALVES AND 90% PHASE SEPARATOR.
- (9) PRESSURE SENSOR, PHASE SEPARATOR SPEED CONTROL AND SENSOR ELECTRONICS (PHASE SEPARATOR NOT INCLUDED).
- (10) PROPORTIONING FLOW SENSOR, CUT-OFF SENSOR AND SENSOR ELECTRONICS.

● RECOMMENDATION FOR BMS

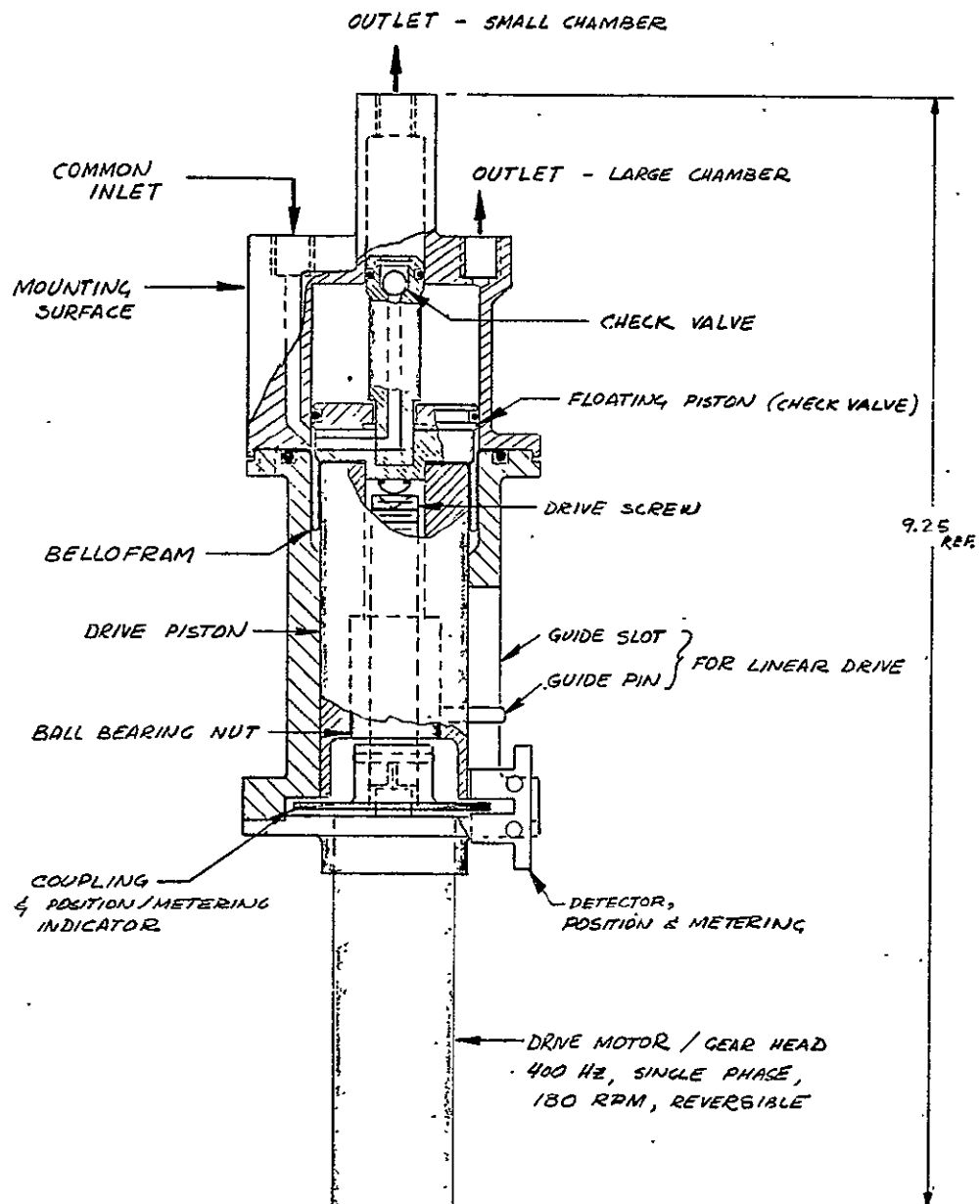
POSITIVE DISPLACEMENT PROPORTIONING FLOW VOLUME SENSOR.

COMBINES VOLUME SENSOR, PUMP AND PROPORTIONING FLOW CAPABILITIES.

CAPABLE OF ACCURATELY (WITHIN 0.25 ml) COMPENSATING 24-HOUR POOL VOLUME FOR FLUSH FLUID DILUTION EFFECTS.

PERMITS IN-PLACE VOLUME REDUCTION.

USED FOR FLUSH WATER DISPENSING CONTROL.



- COMBINED PUMP, VOLUME SENSING AND PROPORTIONING FLOW CAPABILITY
- POSITIVE OPERATION
- SIMPLIFIED MECHANICAL DESIGN
- DERIVED FROM ABSS

Figure 3-12 Positive Displacement Proportioning Flow volume sensor

Note that the estimated error values of the 10% 24-hour pool volume measurement are for individual inputs to the pool. Since the pool is made up of multiple inputs, the total pool volume error will be somewhat less than the values shown.

3.2.1.4 Sampling

Urine sampling involves three separate types of samples as noted in the system performance specification, i.e. microbiological sample, chemical sample and 24-hour pool sample, Table 3-4. The automated approach used for the ABSS, which meets the same general performance requirements, appears appropriate for the BMS. GE report No. 74SD4208, Part I, describes the detail sampling hardware design and operation.

As implemented for the ABSS, the urine microorganism sample container is positioned in the throat area of the urinal. In this position, direct impingement of the incoming urine stream minimizes cross-contamination. Obtaining a microorganism sample is optional and has no effect on the general urine collection process. A recommended refinement for the BMS is inclusion of a nutrient media directly within the sample container. This will simplify use procedures and consequently improve the reliability of obtaining useful samples. As noted above, the microorganism sample is obtained by direct impingement of the urine stream. Ideally, the sample container should be exposed to "mid-stream" urine only since the initial urine flow may not be representative. The basic approach does not prohibit mid-stream sampling; the addition of a mechanism to automatically insert the sample container into the urine stream after the start of micturition would be required.

The ABSS mechanization for automatically obtaining urine chemical and 24-hour pool samples also appears directly applicable to the BMS application. Scaling to

Table 3-4 System Imposed Urine Sampling Requirements

- Micro organism sample (2 ± 1 ml)
Obtain at urinal to minimize cross-contamination
- Chemical sample (5 ± 1 ml)
Water flush required to minimize cross-contamination
- 24-Hour pool sample
Cool to 5°C at collection
10% of each micturition; volume error $\pm 2\%$ (2 sigma value)
Volume reduction to 110 ± 10 ml at 24 hrs.
- Automatic sample container ID
- Samples obtained at user option
- Variable crew size/mission requirements

accommodate 1 to 6 men can be accomplished easily. The associated waterflush and periodic disinfect cycles for minimizing cross-contamination and microorganism control within the system are appropriate. Refinement of the mechanical design is needed to improve probability of reliable operation. It should be noted that flushing the system plumbing, and particularly the plumbing interface with the sample containers, results in considerable mechanical and electronic control complexity but is necessary to achieve the 0.5 ml cross-contamination requirement.

Volume reduction of the 24-hour pool must be accomplished at the end of each 24 hour period. On the average, each 24-hour pool sample container will contain 200 ml. This volume must be reduced to 110 ± 10 ml to reduce on-board storage requirements (see section 3.2.3.4). Although volume reduction was accomplished as a secondary operation in the ABSS, automatic in-place reduction is recommended for the BMS. This will reduce crew involvement and simplify the mechanical design. The increased electronic requirement is compatible with other BMS needs.

In summary, the general sampling mechanization developed for the ABSS appears directly appropriate for the Modular Biowaste Monitoring System application. Some refinement of hardware detail will be desirable.

3.2.1.5 Chemical Analysis

The function of the urine chemical analysis capability is to provide a real time automatic measurement of urine ionic content and pH for each individual micturition as desired. The automated Potentiometric Electrolyte Analysis System designed and built by Orion Research, Inc. (under NASA contract NAS 9-12117) can be adapted to the BMS application. The Orion system is based on the use of chemical

sensing electrode technology. The system design and test performance is described in Orion's final report under contract NAS 9-12117. Performance as reported by Orion for the engineering prototype hardware was within the required specification values, see Table 3-5. The Orion report also notes that if sample size and fluid flow rate restraints are removed, standard deviation of individual electrode measurements can be reduced by about 50%.

The Orion system can be somewhat simplified by leaving out the pCO_2 and Ca_T^{++} capability. This eliminates one electrode assembly, reduces thermal control requirements (the pCO_2 measurement is very temperature sensitive) and eliminates the need for one reagent (acid) needed for Ca_T^{++} measurements. As provided for the engineering model, the valving and pumping hardware is rather complex and should be reviewed for possible simplification. A series of positive displacement metering pumps could replace the current multi-channel pump and multi-function valves for improved reliability and dispensing accuracy. Although the electronic control is fairly complex, the centralized BMS Display/Control function (see section 3.2.3.3) can readily accommodate this capability.

As presently designed, 250 ml each of two reagents and two standardizing solutions are required for every 100 analysis. Scaling this up for a 6 man, 30 day capability will require 3150 ml (6 men x 7 micturitions per day x 30 days x 2.5 ml/sample) each for the reagents and standardizing solutions.

Table 3-5 Specified Chemical Analyzer Performance

<u>Parameter</u>	<u>Precision</u> (larger of two valves)
Na ⁺	± 5% or ± 1 meg/l
K ⁺	± 5% or ±0.1 meg/l
Cl ⁻	± 5% or ±1 meg/l
Ca ⁺⁺ Total	±10% or ±0.1 meg/l
Ca ⁺⁺ Ionized	±10% or ±0.1 meg/l
pH	±.01 pH
pCO ₂	±5% or ±1 mm

3.2.2 Feces Related Elements

3.2.2.1 Collection

The function of the feces collection capability is to automatically collect and retain expelled feces from male and female users and to direct this feces into the feces phase separator. A seat and transport tube assembly make up the basic hardware for feces collection. The requirement for automatic operation eliminates any consideration of previously used bag type approaches (Apollo/Skylab) in favor of the ABSS approach. User interface, transport airflow requirements and disengagement are interrelated key considerations.

The seat performs three basic functions:

1. It positions the user with respect to the collection hardware.
2. It provides an air seal between the collection hardware and the user's anatomy.
3. It stabilizes the user during defecation.

The design of the seat is probably the most influential factor that determines the acceptability of the system hardware to the user. The three parameters listed above must be implemented with the maximum possible comfort and in an earth-like fashion. User positioning with respect to the seat is very important as severe misalignment in excess of 1-1/2 to 2 inches will cause improper performance of the equipment. Lateral positioning is accomplished by referencing the thighs to the sides of the seat. Front to back alignment is accomplished by referencing the lower back to the back of the seat. The distance from the anus to the back of the person in the sitting position is similar regardless of sex or physical build. This alignment is much more precise for the female user as the urinal becomes an additional reference. Vertical positioning and some centering positioning is

achieved by the special torso type zero "g" restraints, see section 3.2.3.5.

Next in importance is the requirement to provide a relatively good air seal around the anal area. This is accomplished by contouring the seat to follow the general anatomical curves, and by making the seat semisoft so that the "giving" of the surface coupled with the natural softness of the user's flesh helps to provide a continuous closed interface. An occasional gap is undesirable, but not critical. Once positioning and sealing is accomplished, the user must be kept in place in a fairly comfortable and stable position. This means that the seat, in conjunction with the torso restraint, must have adequate surface and rigidity to maintain the user balance in a natural way.

Other characteristics required of the seat are compatible with one "g" environment for familiarization and testing, and a common design for male or female use. The female interface may be accomplished by opening the front section of the seat with a 2-1/2-inch wide gap like a regular toilet swing seat, see Figure 3-13. This gap does not cut through to intersect the circular opening in the seat matching the air transport tube. The compliant semisoft material forming the surface of the seat is continued across from side to side at this point to form a barrier which minimizes air leakage for male users and allows the urinal to be positioned properly by deflecting easily for the female users.

Lastly, but not less important, the seat must have a smooth, non-porous surface to minimize contamination, to facilitate periodic sanitation procedures with biocide wipes, and to avoid discoloration by absorption of staining material.

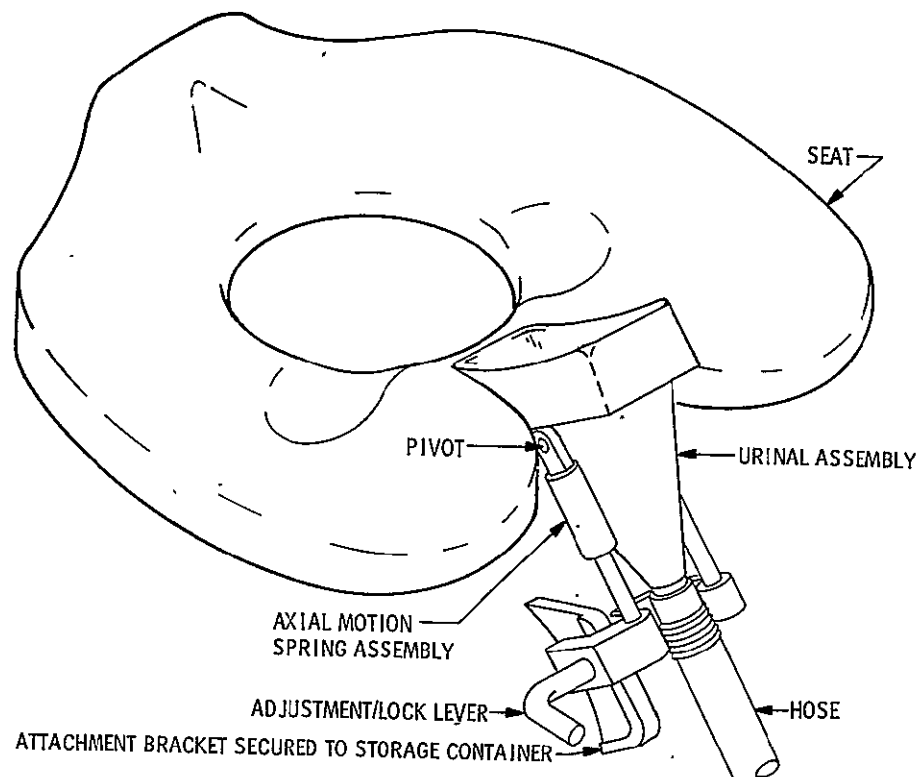


Figure 3-13 Seat/Adjustable Urinal Relationship

The seat is attached to a transport tube which in turn is attached to the feces storage container, see section 3.2.2.5. At the junction of seat and transport tube, transport air jets are provided to disengage (if necessary) and convey the discharged fecal material into the storage container.

The general collection function has been investigated by GE under NASA Contract NAS9-13518. Both laboratory modeling and zero "g" aircraft tests were performed; results are reported in GE Report no. 74SD4221. Briefly, test results indicated that a transport air flow rate of about 30 CFM is required for effective disengagement and transport of the discharged fecal material.

Inertial collection represents an alternate approach to the essentially static collection concept noted above. Inertial collection refers to the use of inertial forces to cause disengagement of the bolus after defecation is completed. The detached bolus is then conveyed by the transport air into the feces storage container. Although several different mechanizations are possible, use of a compressed spring to "power" the inertial collector appears the most desirable. In operation, the spring is compressed by a motor driven cam rotating coaxially with the transport tube and spring. Compressing the spring moves the seat (and user constrained thereto) to the "up" position. Continued rotation of the cam suddenly releases the seat, the compressed spring accelerating the seat (and user) to the desired velocity at the end of the seat travel. The impact at the end of seat travel produces the inertial forces for bolus disengagement. A bread-board model of a compressed spring powered unit has been built and tested by GE under NASA Contract NAS1-11443, Mod. 5S. Although impossible to fully evaluate in a one g environment, test results indicate that satisfactory operation should be obtained in a zero g environment (see GE Report No. 74SD4248).

The inertial collection concept offers some potentially important advantages.

These include:

- (a) a reduction in transport airflow requirements (since the high flow required for bolus disengagement is no longer needed).
- (b) effective sealing between the user and seat (to assure the proper bolus disengagement airflow) is not required,
- (c) a positive bolus disengagement action is provided, and
- (d) an inherent capability for easily generating bolus disengagement forces, if ultimately found necessary, well beyond the practical capability of transport air flow.

These advantages are, of course, obtained at the expense of added hardware complexity.

In summary, the ABSS type passive collection hardware performance for automatic collection has been proven in both laboratory and zero g aircraft tests. The inertial collection concept offers significant advantages albeit at the expense of greater hardware complexity.

3.2.2.2 Phase Separation

The basic function of the feces phase separator is to automatically separate fecal materials, solid or liquid, from the transport air. A secondary function is to distribute the feces within the interior of the feces storage container. This function is accomplished by a motor driven "slinger" assembly. This phase separation concept has been used on ABSS and related systems and proven in zero g aircraft flight tests. The slinger assembly is also a key element in the GE feces mass measurement concept discussed below.

3.2.2.3 Mass Measurement

The function of the feces mass measurement element is to automatically determine the total mass, liquid or solid, of each individual fecal discharge. Two general choices are available for the modular Biowaste Monitoring System, i.e. as a physically separate element or integrated with the collection capability.

The SMMD (Small Mass Measurement Device) developed for the Skylab program is an example of a physically separate device. This approach has several undesirable features. First, whether feces sampling is required or not, a feces sample consisting of the entire defecation must be placed in a sealed sample container. Second, the sample container must be conveyed (manually) to and secured to the SMMD for the mass measurement per se. And third, the sample container and contents must be conveyed to and stored in a suitable waste disposal area in the spacecraft. Practically, bag collection as used for Skylab is needed. Unfortunately, performance and user acceptability of bag collection leaves much to be desired. A variation is to use a calorimeter type device in place of the SMMD. This type device, currently being investigated by Geoscience, Ltd., appears feasible in that total mass inherently is related to the heat content of the feces. It should be noted that any measurement process using thermal energy may destroy the acceptability of the feces sample for most past flight analyses.

The GE feces mass measurement device is an integral part of the collection and phase separator functions. Concurrent feces sampling is not required; no manual transfer of fecal material is required. Operation is entirely automatic, in real time and does not interfere with other functions. The GE feces mass measurement device uses the phase separator slinger assembly as the mass sensing element. The impact of fecal solids or liquid with slinger results in a trans-

fer of energy from the slinger to the feces. By operating the slinger at a constant rotational velocity, the incremental energy input to the slinger drive motor is proportional to the incremental fecal mass passing through the slinger. Total mass is then determined by integration of these incremental power inputs. The GE feces mass measurement concept is currently in the breadboard development stage (NASA Contract NAS1-11443, Mod. 5S). Preliminary test results indicate that measurement of fecal mass with an error of less than $\pm 2\%$ is an attainable goal (see GE Report No. 74SD4248).

In summary, the GE mass measurement concept, although not yet fully proven, offers significant operational and system integration advantages and thus is the concept of choice for the Modular Biowaste Monitoring System application, see Table 3-6.

3.2.2.4 Sampling

The function of the feces sampling capability is to automatically collect and place in a sample container a representative sample (equivalent composition) of the total fecal discharge. A direct and relatively simple approach is to collect the total fecal discharge in a bag type container. This insures a representative sample and eliminates cross-contamination, but leaves much to be desired operationally. To be effective, the bags must pass transport air, but retain fecal solids and liquids. Thus the sample bags must be manually repackaged before placing in storage. Also storage volume requirements are excessive; actually only about 20 grams of fecal material are required for post flight analysis (see GE Report No. 74SD4208, Part II, Appendix 7.5). Further, incompatibility problems with a slinger type collector can be anticipated.

Table 3-6 Feces Mass Measurement Comparison Summary

Item	SMMD	GEOSCIENCE Calorimeter	GE Slinger Power
Real Time Operation	No ¹	No ¹	Yes
Automatic	No ¹	No ¹	Yes
Design Simplicity	-	-	Best
Accuracy	<u>+2%</u>	Unknown	<u>+6%</u> ³
Compatible with			
(a) Feces Sampling	Yes	Yes	Yes
(b) Feces Collectio..	Yes ²	Yes	Yes
State of Development	SKYLAB	Engineering Breadboard	Engineering Breadboard
Weight, Volume, Power	-	-	Least ⁴
User Acceptability	-	-	Best

(1) Manual Transfer by Crew Required.

(2) Requires Use of Bag to Contain Total Defecation, which in Turn Requires Higher Blower Power.

(3) Preliminary Test Results; ± 2% Appears to be an Attainable Goal

(4) Only Power Sensing and Computation Electronics Required.

An alternate approach has been investigated for the ABSS. In this approach, described in GE Report No. 74SD4208, Part II, the sampling function is placed downstream of the slinger. Samples are obtained by automatically deploying from the sample container a collection strip (2 inches wide x 6 mil stainless steel) in a manner to partially or completely surround the slinger. All (or part) of the fecal material which passes through the slinger is intercepted by the collection strip (depending on the length deployed). The collection strip is then automatically returned to the sample container. With this technique, sampling does not interfere with real time automatic feces mass measurement. Since total feces mass is known, only a minimal size sample is necessary which thus minimizes storage requirements (assuming uniform distribution by the slinger).

The collection of fecal waste for the quantification and identification of anaerobic type bacteria appears to be a practical impossibility for the Modular Bio-waste Monitoring System. To prevent loss of viable species of anaerobes, the entire collection and sampling process must be accomplished in the complete absence of oxygen. Further, preservation for periods exceeding 3-5 days has not been accomplished. Comparatively, obtaining samples for the quantification and identification of aerobic bacteria species may be readily obtained as part of the sampling procedure noted above.

In summary, the ABSS collection strip approach provides for automatic total or partial sampling of fecal wastes without interference with feces mass measurement or other functions. The collected fecal material may be used for chemical and aerobic bacteria identification and analysis and for moisture content determination. Sampling for anaerobic bacteria does not appear practical for the BMS application.

3.2.2.5 Storage

The function of the BMS feces storage element is to contain and microbiologically deactivate the fecal material (not removed as samples) and used tissues. The feces storage container exemplified by the ABSS design and proven in zero g aircraft flight tests is applicable to the BMS. An oblate spheroid shaped container with about 2.4 ft³ free volume will be required for a full 180 man-day usage. This size is based on 30- and 90-day chamber tests of comparable designs. Additional design details including a tissue by-pass arrangement (to prevent mixing of tissue and fecal samples) are discussed in GE Report No. 74SD4208, Part II. It should be noted that the feces storage container detail design is largely controlled by the collection and phase separation modes selected and by the physical size range of the users.

Deactivation of the fecal microorganisms may be accomplished by heating (wet/dry), desiccation, chemical disinfection, refrigeration, radiation and aerobic or anaerobic digestion. Based on an analysis for the ABSS (see GE Report No. 74SD4208, Part II, Appendix 7.5), desiccation by air or vacuum drying were about equally advantageous. Air drying was selected for the ABSS on the presumption that overboard dump of fecal vapors would not be permitted. Such is not the case for SHUTTLE, thus the vacuum drying approach is appropriate for the Modular Biowaste Monitoring System. This reduces input electric power (to operate the blower during air drying) and reduces the size of the odor filter.

3.2.3 Common Elements

3.2.3.1 Air Flow Generation

A blower/motor assembly is required to provide the transport air flow needed in the urine and feces collection process. Blower flow capacity and total system pressure drop are key considerations. The air flow/pressure drop diagram of Figure 3-14 is typical of what can be expected for the BMS application. No problems are anticipated in selecting a blower/motor assembly compatible with the anticipated BMS air flow and pressure drop requirements.

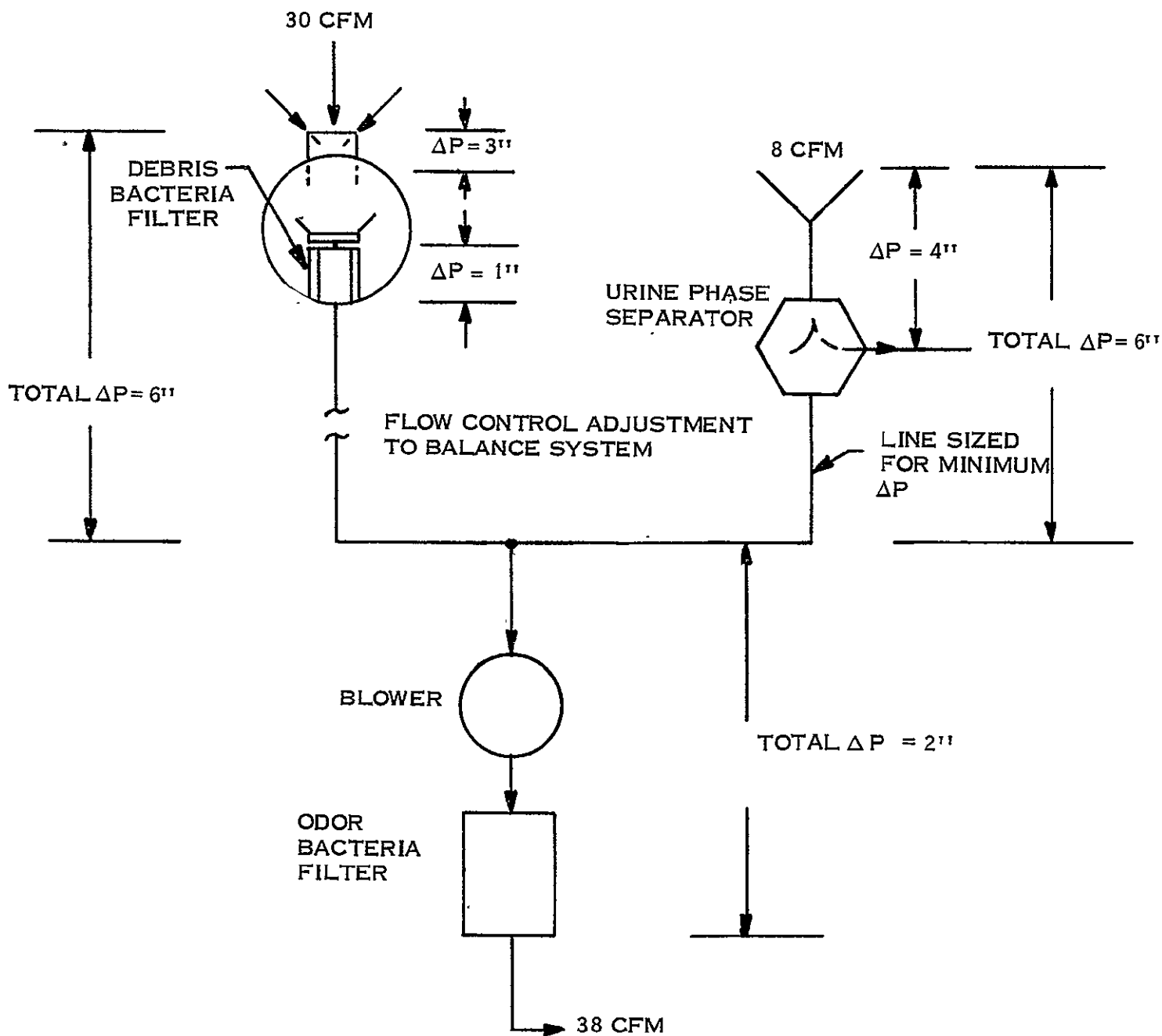
3.2.3.2 Odor/Microorganism Control

An odor/microorganism filter capability is required to condition the transport air prior to return to spacecraft ambient. The filter also serves to reduce noise generated by the air blower. This combined function device exists in a highly developed hardware state. Replacement after each mission is anticipated. Charcoal is recommended for odor control; Purafil is rejected due to lack of flight experience and known dusting problem. The microorganism control portion of the filter typically will have a bacteria removal rating of 99.5%. It should be noted that the probability of bacteria in the urine transport air flow is very low due to the repeated flush and disinfect cycles, see section 3.2.4.1. Also a second microorganism filter is located in the storage container to prefilter the feces transport air, see Figure 3-14.

3.2.3.3 Control Display

3.2.3.3.1 Control

The programmer, supplemented by power conditioning circuitry, controls the various



NOTE: PRESSURE DROP IN INCHES OF WATER

Figure 3-14 Typical Air Flow/Pressure Drop Diagram

system operations. Thus, on cue from the user, the programmer automatically directs urine collection, volume measurement and other system functions. The various system sensors and position switches provide feedback information to the programmer. This information is electronically correlated against stored instructions, the results of the correlation being used as the basis for the next instruction issued by the programmer.

The programmer may be designed for a single fixed set of instructions or programmable (via software) so that the instructions can be altered to fit specific mission requirements. The ABSS programmer is an example of the former. The use of a microprocessor with a programmable read only memory (PROM) capability is an example of the latter. On a smaller scale, the latter approach was used on NASA Contract NAS1-11443, Mod. 5S, in conjunction with feces mass measurement breadboard tests.

The programmable type approach (containing the necessary elements for controlling the complete capability BMS) is recommended. The inherent flexibility via software of reprogramming for specific mission requirements and adding future control features, without revising the hardware, is a major advantage. Note that hardware revisions can effect the flight qualification status of the programmer whereas software changes will not.

3.2.3.3.2 Display

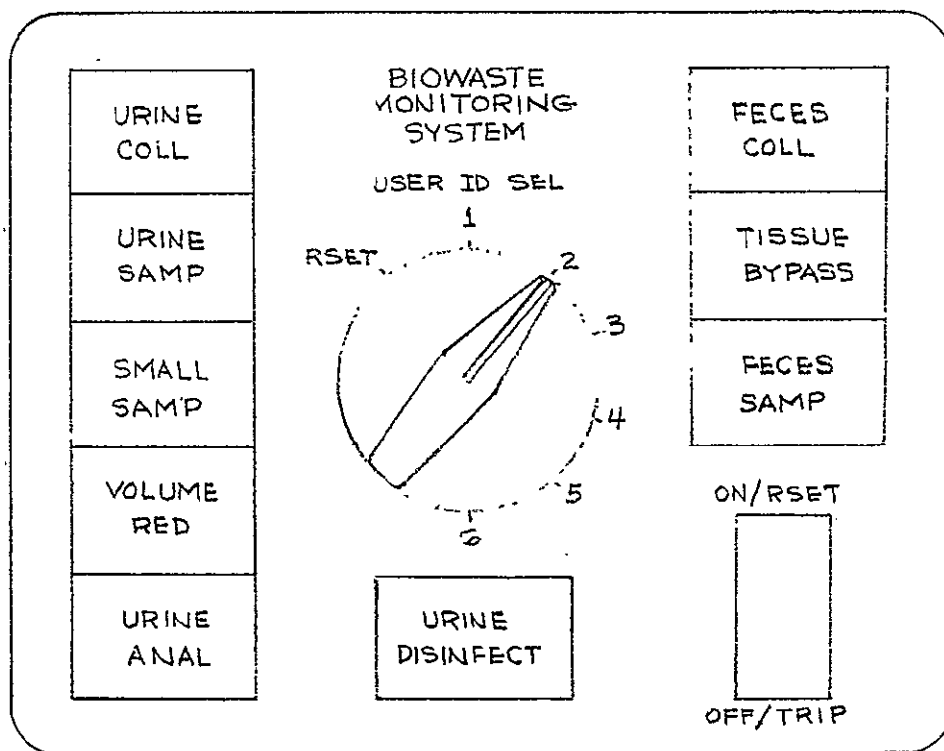
The display provides the operating interface between the user and the system and thus provides system operating information to the user and means for the user to initiate specific actions by the system. Two types of display elements were considered; status lights and data readout recorders. Status lights inform the operator that the system is ready to use and that operation is proceeding normally or

that corrective action by the user is required. A hard copy printer was considered as a data readout recorder (for recording urine volume, feces mass and sample container numbers), but rejected for the following reasons:

- (a) The user has no need for this data for operating the BMS. Providing data to the user which does not require an action on his part is poor human engineering design.
- (b) The user may try to interpret the data (for example, urine volume) and then adjust his actions (by drinking more or less water) which could confound the experiment.
- (c) Similarly, user(s) may engage in "competitions" (e.g. maximum urine volume per micturitions) which could also confound the experiment.

Rather than a hard copy recorder, interfacing with the SHUTTLE TLM capability is recommended. This eliminates a relatively complicated hardware element (printer) requiring periodic servicing (tape installation). Telemetry automatically and in real time supplies the experimenter with the raw data for his expert interpretation. The printer tape record is available only post flight or via periodic voice communication from the SHUTTLE crew.

Figure 3-15 illustrates a possible layout for the BMS control panel. Inclusion of the total BMS capability (as with the control electronics) is recommended. Those elements not required for a specific mission would be inoperative. The general design is similar to that used on the ABSS program. Thus the USER ID SEL switch requires rotation to the RESET position before setting to the user's ID number.



- COMBINED LEGEND/SIGNAL LIGHT TYPE PUSHBUTTON SWITCHES
- CKT BKR PROVIDES PWR ON-OFF FUNCTION
- EGG-CRATE TYPE BARRIER
- PROVIDES TOTAL BMS CAPABILITY

Figure 3-15 BMS Control Display Panel Layout (Preliminary)

3.2.3.4 Sample Storage

Table 3-7 lists the storage temperature and storage volume required for each type of sample. For a maximum mission capability (6 men, 30 days), the total volume needed is a rather formidable 7.8 ft^3 . Adding an allowance for packing inefficiency and the refrigeration hardware increases the total storage volume required to about 12.0 ft^3 . Since this represents the maximum requirement, dividing this volume into 2, 3 or 4 equal parts to fit a reduced mission capability is appropriate. Two 6 ft^3 (1/2 the maximum capability) units were selected as a first cut for the BMS. Further, to simplify this initial analysis, storage at $+4^\circ\text{C}$ and -70°C only was considered. Also because of sample container materials and flexible shape, forced circulation of air within the storage compartment (to cool the sample containers) was selected over cold plates. This also improves packing efficiency and reduces overall weight of the storage cabinet. Figure 3-16 shows the refrigerator cabinet and estimated cooling load for one unit. Note that the cooling load is largely dependent on the insulation loss (2 inch thick polyurethane or equal, $k = 0.2 \text{ BTU/in. hr. ft}^2\text{F.}$, assumed).

A number of refrigerations techniques are potentially applicable. Three of these are examined in some detail. A fourth, use of a space radiator, was rejected as an impractical interface with the SHUTTLE. Use of a space radiator would also impose unrealistic operational restrictions on orbit altitude and spacecraft attitude.

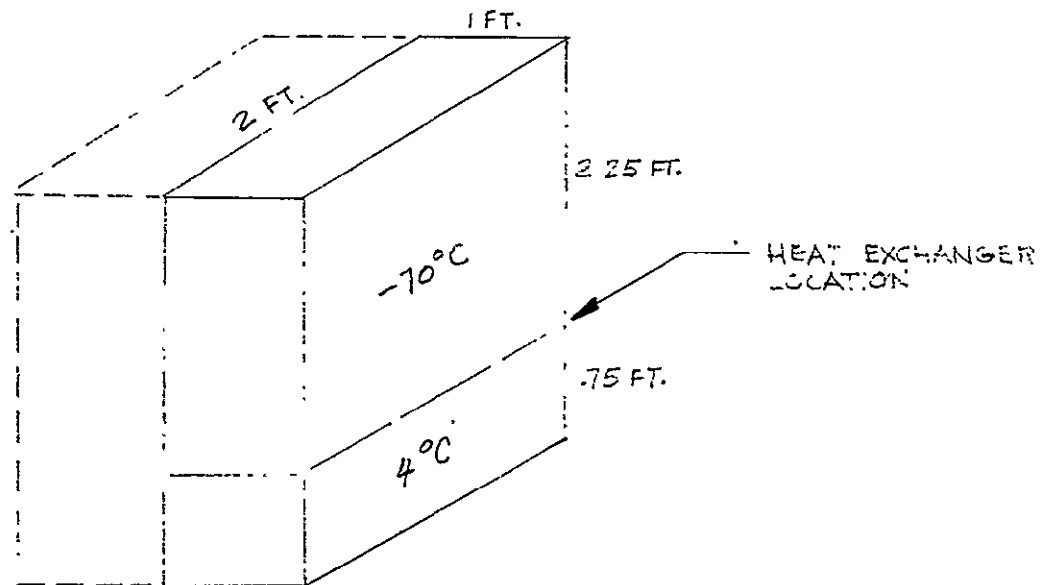
Figure 3-17 illustrates the use of an expendable refrigerant. In this approach a suitable liquid is evaporated in the storage cabinet heat exchanger, the resulting vapor (and heat) being dumped to space vacuum. The refrigerant must be liquid at the lowest storage cabinet operating temperature (-70°C) and exhibit a high heat of

TABLE 3-7 SAMPLE STORAGE REQUIREMENTS

TYPE SAMPLE	SIZE	NUMBER REQ'D ⁽¹⁾	TOTAL VOLUME	STORAGE TEMPERATURE
URINE SAMPLES				
MICRO-ORGANISM	1 x 1 x 3.5 INCH	1260	4410 IN. ³	4°C
CHEMICAL (5 ML)	1 x 1 x 3.5	1260	4410	-20/-70°C
10% 24-HOUR POOL	1 x 2 x 7	180	2520	-20/-70°C
FECES SAMPLE	2.5 x 2.5 x 2	180	2250	-70°C
TOTAL	N/A	2880	13590 IN. ³ (7.8 FT. ³)	N/A

(1) 6 MAN-30 DAY CAPABILITY

- TWO UNITS, 6 FT³. EACH INCLUDES PACKAGING ALLOWANCE



- ESTIMATED COOLING LOAD (ONE UNIT)

	<u>-70°C SECTION</u>	<u>+4°C SECTION</u>
INSULATION LOSS	600 BTU/HR	79 BTU/HR
FAN	10	10
SAMPLES	15	1
	<u>625 BTU/HR</u>	<u>90 BTU/HR</u>

Figure 3-16 Refrigerator Cabinet Size and Cooling Load

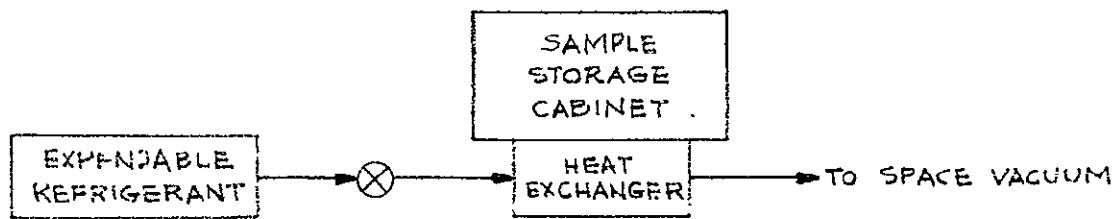


Figure 3-17 Expendable Refrigerant

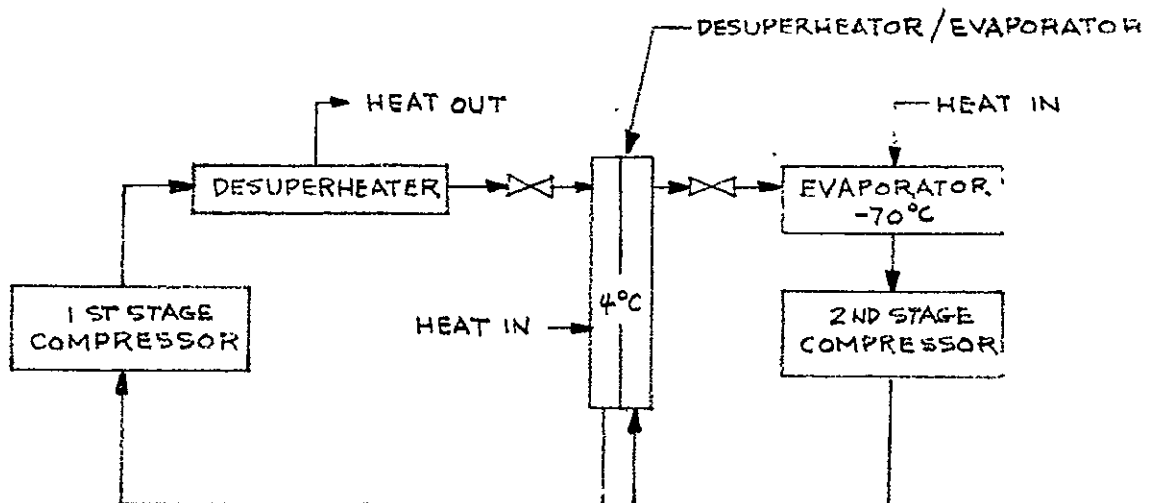


Figure 3-18 Two Stage Freon Cycle

vaporization. The refrigerant must also be non-toxic. As a first cut, Freon was selected as the refrigerant. With a heat of vaporization of about 100 BTU/lb, the 715 BTU/hr. cooling load for one of the unit storage cabinets, see Figure 3-16, would require 7.15 lbs. of Freon evaporated per hour. For a 30 day, 6 man sample load, a prohibitive 10,300 lbs. of Freon would be required.

The use of thermoelectric elements was also investigated and rejected. Based on Cambion catalog data, seven thermoelectric stages would be required for operating between +38°C (100°F) and -70°C and maintaining the COPR at about 100%. For this condition, some 437 TE elements are required with a total power input of 1307 watts. Although seven stages is not necessarily optimum, substantial improvement appears doubtful. If the number of stages is reduced, the COPR drops below 100% and thus more power is required per stage. If additional stages are added, the COPR improves so that less power is required per stage. In either case, the improvement in one factor is offset by a loss in the other factor.

Figure 3-18 illustrates a two stage Freon cycle. As a first cut, the first stage evaporator was assumed to be operating at +4°C, the upper sample storage temperature. Table 3-8 shows the results of the corresponding analysis. Some reduction in input power can be obtained by a more optimum load balance between the two stages. Operating the first stage down to -15°C instead of +4°C reduces overall power input to 145 watts from 174 watts (for one storage unit). The analysis results shown are for the storage units only. Precooling of the 24-hour pool samples can also be accomplished with the same refrigeration capability. This will add about a 7 watt power input for the +4°C first stage or 13.7 watts for a -20°C first stage (the difference is due to the change in effective COP for the two operating conditions). Note that sampling module No. 4 (Section 3.3.2) will always require the presence of a storage module (one or both units) in the BMS.

TABLE 3-8 TWO STAGE FREON CYCLE ANALYSIS

2ND STAGE

Temperature Range	+4°C To -70°C
Cooling Load	
Cabinet Loss	178.0 watts
Samples ⁽¹⁾	4.6
Fare	<u>3.0</u>
	185.6 watts
Effective COP ⁽²⁾	1.38
Power Input	135.0 watts

1ST STAGE

Temperature Range	+39°C To +4°C
Cooling Load	
Cabinet Loss	23.2 watts
Samples ⁽¹⁾	0.3
Fan	3.0
2nd Stage	<u>135.0</u>
	161.5 watts
Effective COP ⁽²⁾	4.2
Power Input	39.0 watts
Total Power Input	174.0 watts ⁽³⁾

(1) 3 Man, 30 Day Capability

(2) 50% of Theoretical COP

(3) For one Storage Unit

The use of the Freon vapor cycle may represent a safety hazard depending on the spacecraft environmental control equipment used for toxic gas control. If a catalytic burner is used for this purpose, phosgene may be generated from Freon passing thru the catalytic burner. An alternate means of toxic gas control can eliminate this hazard. Also, Freon leakage is easily detected by halogen sensors. If leakage did occur, the catalytic burner could be deactivated and the Freon purged from the spacecraft atmosphere.

In summary, a sample storage module composed of two identical units of 6 ft³ storage capacity each with heat rejection via a 2-stage Freon cycle is recommended. Sufficient refrigeration capacity for pre-cooling the 24-hour pool samples can be included. Weight and power input are significant, particularly power, and may not be compatible with SHUTTLE support capability. A relook at sample size and collection frequency is recommended prior to detail design of this module. Although Freon vapor cycle equipment is not currently available for space flight use, design for the zero gravity environment does not appear to be unrealistic.

3.2.3.5 Restraint

A user body restraint capability is necessary for effective user operation of the Modular Biowaste Monitoring System. Conventional hand hold restraints, an automatic stowing waist restraint on the commode and separate "Dutch Shoe" restraints for further stabilization appear to be a desirable combination. These restraint mechanisms are shown in Figure 3-19 and further described below.

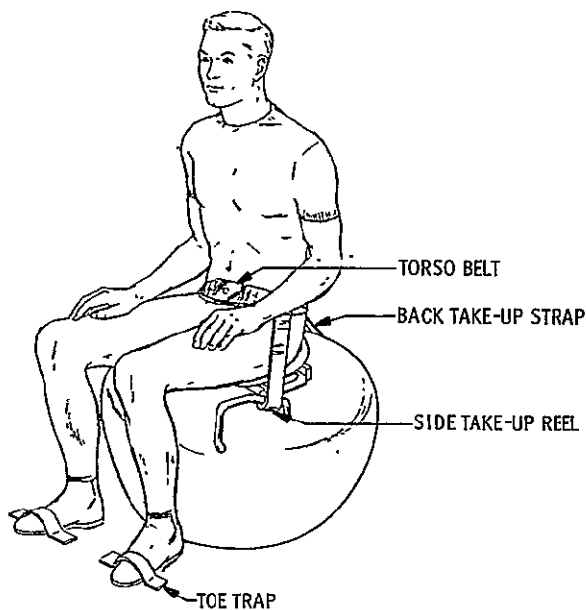


Figure 3-19 Restraint Assembly

The hand hold restraints are multi purpose and can be used for positioning or actual stabilization at the option of the user during use of the urinal or fecal collection sequences.

The waist restraint circles the user at the waist just above the iliac crests and is attached to the feces storage container by three webbed belts, one at the back of the seat and two at lateral positions. Spring take-up reels remove slack in the webbed belts and exert an evenly distributed downward force on the user toward the seat. The combined action of the take-up spring provides a

"downward" force on the user which is sufficient to ensure an adequate seal between the buttocks of the user and the seat. The method of attachment of the waist restraint aids in positioning (centering) the user on the seat; the automatic take-up feature allows the user to comfortably move or reposition on the seat with no additional manipulations or adjustment of the restraint being required. The take-up feature also provides for automatic stowage of the webbing and waist belt providing easy accessibility to the user and preventing possible contamination of the restraint belts. The waist restraint is easy to use; the user positions and locks the restraint with one simple motion.

A single set of Dutch shoe type restraints are provided for both seated and standing use of the system. These serve as an additional optional restraint for the seated user but may be also used by male or females for "stand up" urination.

3.2.4 Ancillary Elements

3.2.4.1 Flush Fluid Supply

To minimize cross-contamination between individual samples, a water flush is required following each micturition. The magnitude of the urine residual remaining in the urinal, phase separator, volume sensor and connecting lines determines the amount of water and number of rinses required per flush cycle. Assuming a urine residual of 10 ml (12 ml for ABSS), a single rinse using 190 ml of flush water will be required to reduce sample cross-contamination to less than the required 0.5 ml. A dual rinse uses considerably less flush water, see Table 3-9, but at the expense of longer cycle time and more complex control. Thus at the end of a dual flush cycle of two 34.7 ml rinses, the system residual will consist of 9.5 ml of flush water and 0.5 ml urine. It should be noted that the flush water must be of known composition in that the total residual will be mixed with the next micturition and appear in any samples obtained. Note also that the above water flush values apply to 24-hour pool and chemical sample cross-contamination only. Urine residual has no effect on urine microorganism samples.

The flush water supply hardware can be relatively simple consisting of a reservoir (with an internal collapsible bladder) and discharge pump. This type arrangement is preferred over a pressurized reservoir/solenoid valve combination in that access to a source of high pressure gas (20-30 psi) is not required (and which is not currently available on SHUTTLE). The reservoir is vented to ambient thru a porous hydrophobic filter vent plug, designed to constrain liquid to the inside of the reservoir in case of bladder failure. Multiple reservoirs can be provided to accommodate varying mission flush water requirements. About 90 liters of flush

Table 3-9 Flush Fluid Requirements

Cross-Contamination

- Requirement - 0.5 ml maximum urine carryover to next sample.

Micturition Volume	40 ml Rinse (5/1 Dilution)	Contamination of Subsequent Micturition ¹		
		90 ml Rinse (10/1 Dilution)	190 ml Rinse (20/1 Dilution)	Two 34.7 ml Rinses (20/1 Dilution)
50 ml	2.0 ml	1.0 ml	0.5 ml ²	0.5 ml ²
100	1.0	0.5	0.25	0.25
200	0.5	0.25	0.125	0.125
400	0.25	0.125	0.063	0.063
800	0.125	0.063	0.032	0.032

(1) Assuming 10 ml Urine Residual Before Flush Cycle

(2) Equivalent to 1% Contamination

- 90 Liters Water Required for 6 Man - 30 Day Mission
- Four 22.5 Liter Tanks

water will be required for a full 6 man-30 day mission. The above presumes that on-board condensate or fuel cell water are not available for use or chemically acceptable as a supply of flush water. If these alternate sources are available and acceptable for use and can be supplied under pressure, than the design and size of the flush water capability can be greatly simplified.

Although a water flush is only required if the next micturition is to be sampled, experience has shown that a periodic water flush is useful for minimizing microorganism growth and odor resulting from urine constituent breakdown. Further, to prevent microorganism growth build-up within the system and in the excess urine waste storage tanks, a biocide must also be added periodically. For the maximum 6 man, 30 day mission, some 3.6 liters of Betadine biocide (a 30% solution containing 3% available iodine) are required. Betadine is biocidal to bacteria, fungus, protozoa, yeasts and essentially any microbial form associated with urine collection and disposal. An estimated 300 ppm available iodine (a 100 to 1 dilution) will be adequate to stabilize urine. Thus the total volume for a 6 man, 30 day mission is then 180 man-days X 2 liters/ man-day X 1/100-3.6 liters of biocide.

Ideally, the biocide should be mixed with flush water and injected into the system thru the urinal. However, if injected after each micturition, the resulting iodine concentration in the residual could interfere with subsequent analysis of the chemical and 24-hour pool samples. This factor was resolved in the ABSS by providing a special disinfect cycle. This cycle included biocide/flush water injection and a soak period followed by sufficient water rinses to reduce the iodine concentration in the residual to under 10 ppm. As shown in Table 3-10, four 64 ml rinses are recommended for the BMS (assuming a 10 ml system residual). This general approach

Table 3-10 Microorganism Control

- Functions - Disinfect BMS and Stabilize Urine During Storage.
- Periodic Biocide Addition (120 ml - Once Per Day)
 - 30% Betadine (3% Available Iodine)
 - 3.6 Liters for 6 Man - 30 Day Mission (100/1 Dilution)
 - Four 0.9 Liter Tanks
- Flush BMS After Biocide Addition
 - Prevent Iodine Contamination of Subsequent Urine Samples
 - Reduce Iodine Concentrate from 30000 ppm to 10 ppm Via
Water Flush

Rinse Cycles	Water Volume Per Rinse Cycle	Total Water Volume
2	538 ml	1076 ml
3	134	402
4 ¹	64	256
5	40	200

(1) Recommended

is further described in GE report No. 74SD4208, Part I. As with the water flush supply, a bladder type biocide reservoir and metering pump will be required to implement the concept.

3.2.4.2 Waste Liquid Disposal

After the measurement, sampling and analyzer functions, excess urine, flush water and analyzer fluids must be removed from the system hardware and rejected to the SHUTTLE waste liquid storage tanks. This action must be accomplished in a manner which minimizes the liquid residual left in the system (in order to reduce cross-contamination). Purging the system hardware with air in conjunction with appropriate line size, etc. selection is required. Based on experience with the ABSS, a liquid residual of about 10 ml can be anticipated.

Although purging with air is reasonably effective in minimizing residual, the presence of air with the waste liquid represents a complication for the SHUTTLE application. This is because the SHUTTLE waste liquid storage tanks cannot contain more than 5% air (by volume). On the average then, 100 ml ($2000 \times .05$) of air per man-day is acceptable. This compares with a purge air requirement ranging from about 625 ml to 1575 ml per man-day depending on the size and number of micturitions (based on ABSS experience). Thus, removal of the purge air from the waste liquid is required.

Figure 3-20 illustrates the hardware relationships. Several potential options for providing this additional phase separation function are available. First, if the BMS is located contiguous to the SHUTTLE WCS, the WCS urine phase separator and pump can be used. A possible alternate is to use the S/C ECS condensate phase separator. This, of course, presumes that an interconnection between the BMS and WCS

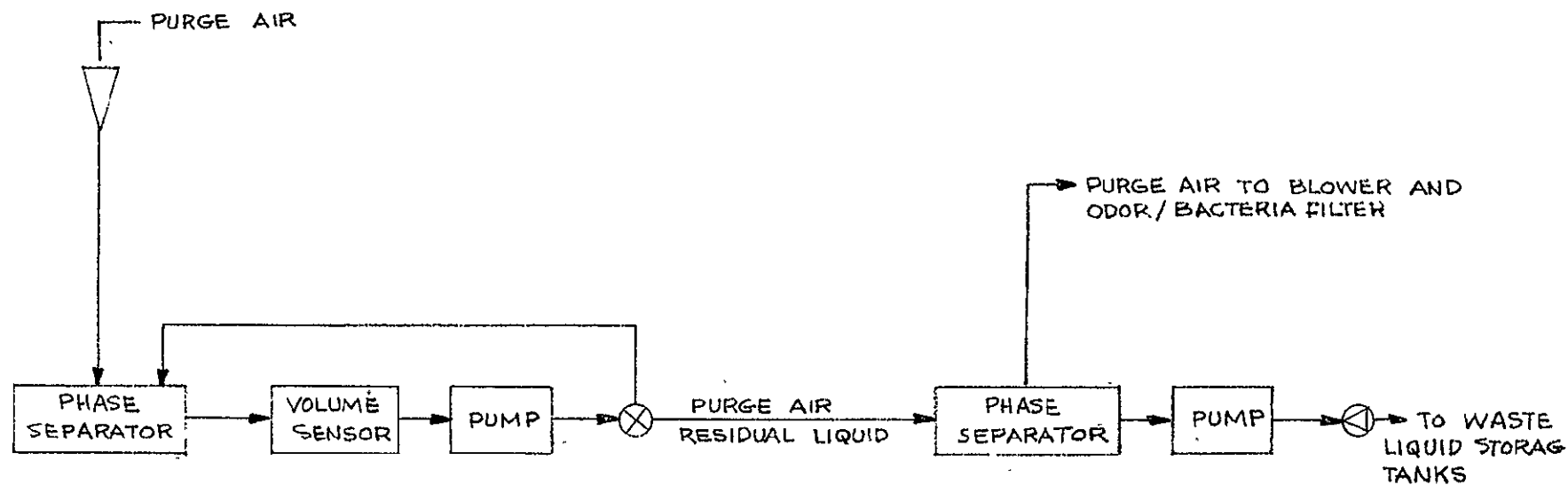


Figure 3-20 Waste Liquid Disposal

(or ECS) systems is practical (a likely situation) and that there are no operational restrictions on the simultaneous operation of the two systems.

If a contiguous location is not possible, e.g. the BMS may be located in the Spacelab and not the ORBITER, then the second phase separator and pump as shown in Figure 3-20 must be provided as part of the BMS. This second phase separator/pump combination could be identical to or a redesigned (smaller) version of the initial urine phase separator and pump arrangement.

A third possibility, dump of the purge air and corresponding waste fluid to the feces storage container or equivalent, was also investigated. This approach is of doubtful practical use in that it requires the evaporation of an additional 840 ml (50 ml urine plus 2-34.7 ml water rinses per micturition) of fluid per man-day (average) from the feces storage container to space vacuum. This is some 10 times the evaporation capability required for feces only and thus may not be compatible with the SHUTTLE vent capability.

The above evaporation requirements assumes a water flush is used after each micturition to prevent sample cross-contamination. If only urine collection and volume measurement functions are required, the water flush could be eliminated leaving 350 ml of urine average per man-day (assuming a 50 ml cut-off) to be evaporated in the feces storage container. This smaller amount may be acceptable.

The proceeding discussion presumes that the S/C waste liquid storage tanks are adequate in size to accommodate the BMS waste liquid. If this is not the case, further consideration for using on-board condensate or fuel cell water (for BMS flush water) should be made.

In summary, the disposal of liquid wastes to the SHUTTLE waste liquid storage tanks requires an auxiliary phase separator to remove purge air from the waste liquid or operation of the BMS contiguous with and in conjunction with the SHUTTLE WCS. Use of the ECS condensate phase separator may be a possible alternate.

3.3 System Synthesis

3.3.1 General

The Modular Biowaste Monitoring System (BMS) concept is intended to provide a total urine and feces monitoring capability in discrete subsystem units, i.e. modules, so that the system capability may be scaled up or down to meet specific requirements of each SHUTTLE mission. With a 100 mission life planned for SHUTTLE, large variations in urine and feces monitoring requirements can be expected.

Modularity as applied to the BMS is achieved by an appropriate selection of standardized functional elements which, together with interconnecting plumbing and wiring, form the BMS capability for meeting a specific mission need. In general, as the capability need is scaled up or down, a different interconnecting plumbing and wiring assembly tailored to that specific combination of modules will be required. Also, modularity does not imply or require that the concept or components selected for a specific individual module be the optimum selection for that module. Rather the selection of a specific concept or components, must be optimum for the total system. Thus a specific module may have capability in excess of that required to perform the basic module function but required for total system capability. Similarly more complex, higher power, etc., equipment may be required because of total system needs.

3.3.2 Recommended System

Grouping the system functions discussed in section 3.2 into logical modular units was based on experience and BMS unique requirements. Table 3-11 lists and figures 3-21 thru 3-34 describe the resulting modules which may be combined, totally or in part, to form a BMS capability. Figure 3-35 illustrates the recommended BMS Urine S/S baseline capability. This baseline provides for urine collection and volume measurement of individual micturitions, functions which will be required on any mission involving urine monitoring. Figures 3-36 thru 3-39 show the BMS Urine S/S baseline with other modules added to accomplish sampling and/or chemical analysis. Other combinations are possible. Similarly, Figure 3-40 shows a BMS Feces S/S baseline. As for urine, this baseline provides for collection and mass measurement of individual defecations, functions that will be required on any mission involving feces monitoring. Figure 3-41 shows the BMS Feces S/S baseline with feces sampling and sample storage added.

Figure 3-42 illustrates the total BMS capability. Estimated weight and power requirements, as for Figures 3-21 thru 3-41, are for the maximum 6 man, 30 day capability. Note that the flush fluid and sample storage modules may be used in sub-module sizes if less than the 6 man, 30 day capability is needed. For each operational combination selected, Figure 3-42 or less, the control/display module programmer will be reprogrammed to meet requirements of the corresponding mission. This reprogrammable feature provides an additional degree of operating flexibility.

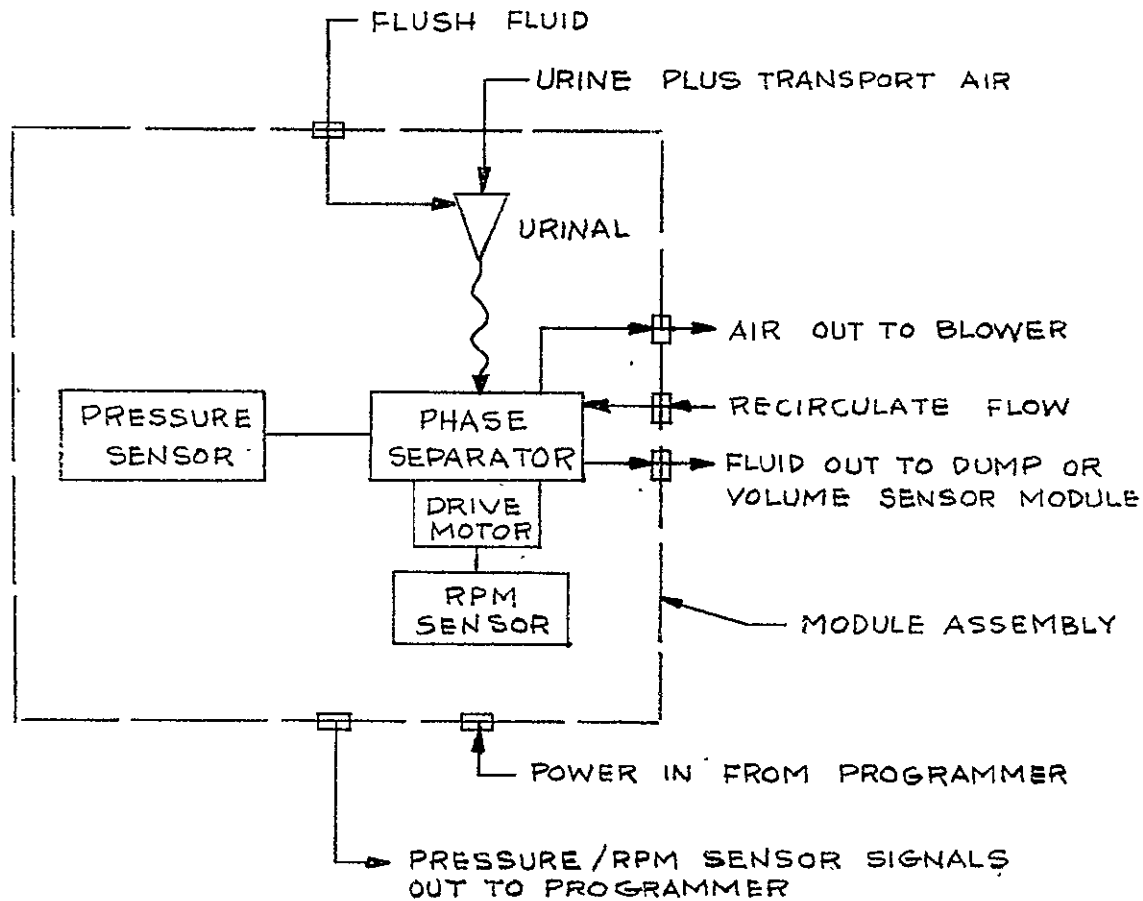
TABLE 3-11 MODULE HARDWARE CONCEPT SELECTION SUMMARY

MODULE FUNCTION	CONCEPT SELECTION PRIMARY SOURCE
URINE COLLECTION	NAS 1 - 11443 ⁽¹⁾
URINE VOLUME MEASUREMENT	NAS 1 - 11443
URINE SAMPLING	
MICROORGANISM	NAS 1 - 11443
CHEMICAL	NAS 1 - 11443
24-HOUR POOL	NAS 1 - 11443
URINE CHEMICAL ANALYSIS	NAS 9 - 12117 ⁽²⁾
FECES COLLECTION	NAS 1 - 11443
FECES MASS MEASUREMENT	NAS 1 - 11443
FECES SAMPLING	NAS 1 - 11443
AIR FLOW/ODOR CONTROL	NAS 1 - 11443
DISPLAY/CONTROL	NAS 1 - 11443
SAMPLE STORAGE	NAS W - 1562 ⁽³⁾
4°C	
-20°C	
-70°C	
FLUSH FLUID	NAS 1 - 11443

(1) AUTOMATED BIOWASTE SAMPLING SYSTEM (ABSS); GENERAL ELECTRIC COMPANY. NOTE: ABSS DESIGNED TO BE PRECURSOR TO BMS.

(2) AUTOMATED POTENTIOMETRIC ELECTROLYTE ANALYSIS SYSTEM; ORION RESEARCH INCORPORATED.

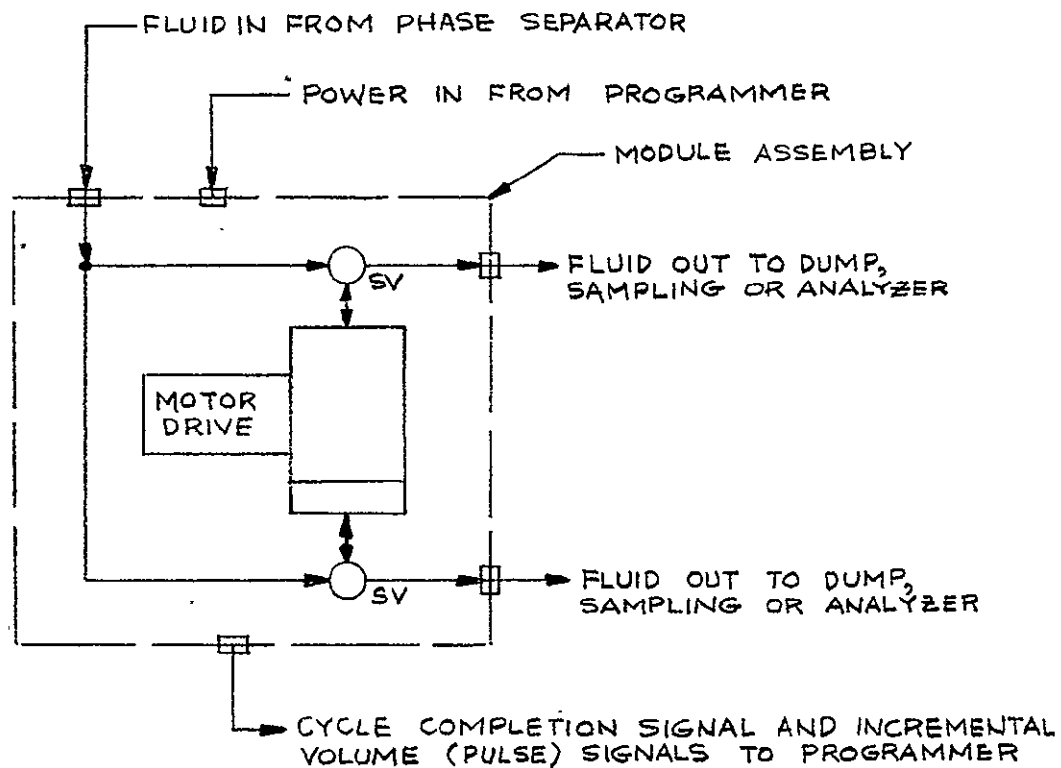
(3) COLLECTION AND PRESERVATION OF BIOLOGICAL SPECIMENS DURING SPACE FLIGHT; GENERAL ELECTRIC COMPANY.



- PRESSURE/RPM SENSORS PROVIDE MALFUNCTION ALARM SIGNALS (FLUID LEVEL/PHASE SEPARATOR ROTATION).
- PRESSURE SENSOR OUTPUT SIGNAL ALSO USED DURING VOLUME SENSING/SAMPLING CYCLES.
- ESTIMATED (FLIGHT DESIGN)

WEIGHT	15.3 LBS
POWER	37 WATTS PEAK
- DERIVED FROM ABSS PROGRAM.

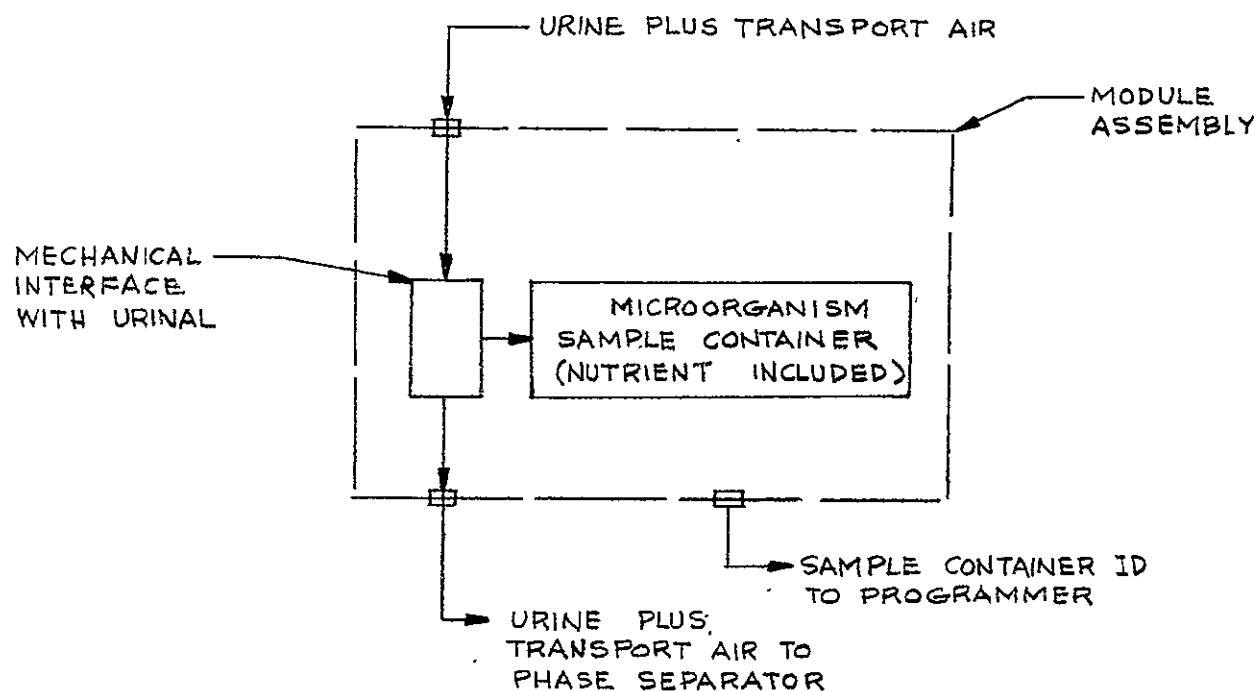
Figure 3-21 BMS Urine Collection Module



- MODULE ALSO INCLUDES 10/1 FLOW PROPORTIONING AND AIR/LIQUID PUMPING CAPABILITY
- ESTIMATED (FLIGHT DESIGN)

WEIGHT	4.54 LBS.
POWER	14.0 WATTS (PEAK)
- DERIVED FROM USCS/ABSS PROGRAM

Figure 3-22 BMS Urine Volume Sensor Module

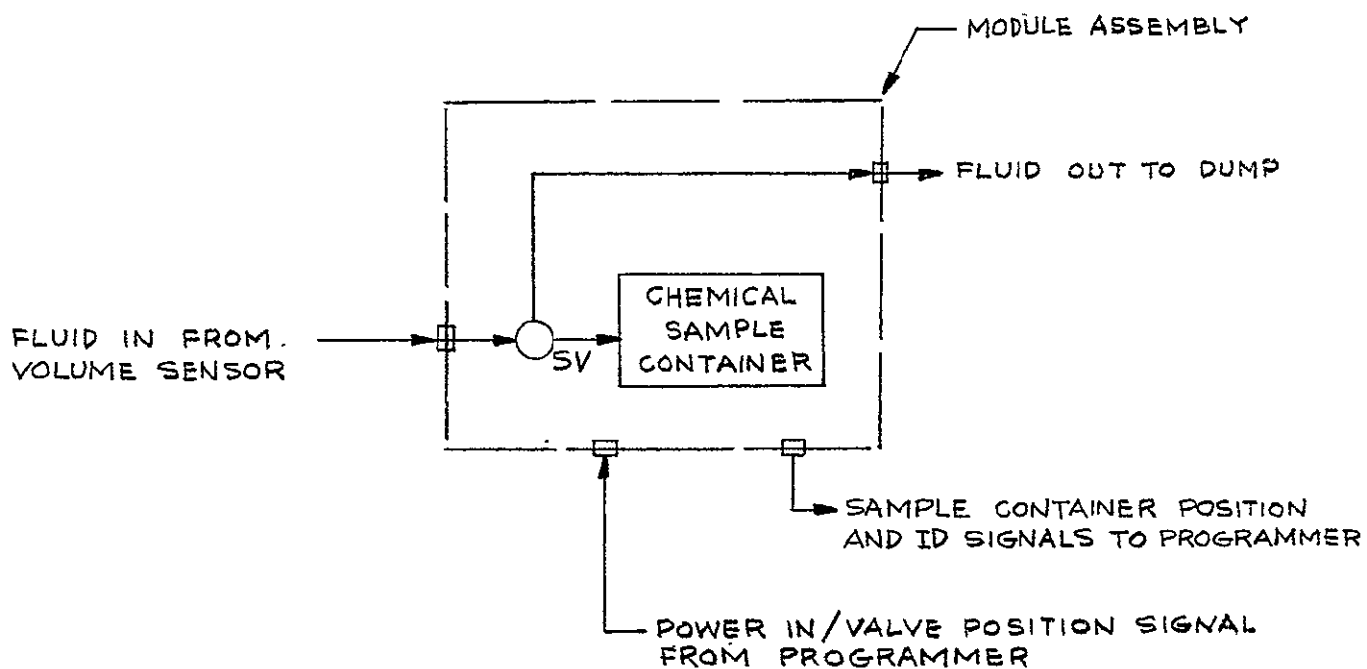


- 2 ml MICROORGANISM SAMPLE (USER OPTION)
- SAMPLE CONTAINER LOCATED IN URINAL OPENING
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>SAMPLE CONTAINER</u>
WEIGHT	0.20 LBS.	0.10 LBS. (EACH)
POWER	0.00 WATTS	N/A

- DERIVED FROM ABSS PROGRAM (MID-STREAM SAMPLING NOT REQUIRED)

Figure 3-23 BMS Urine Sampling Module - Option No. 1

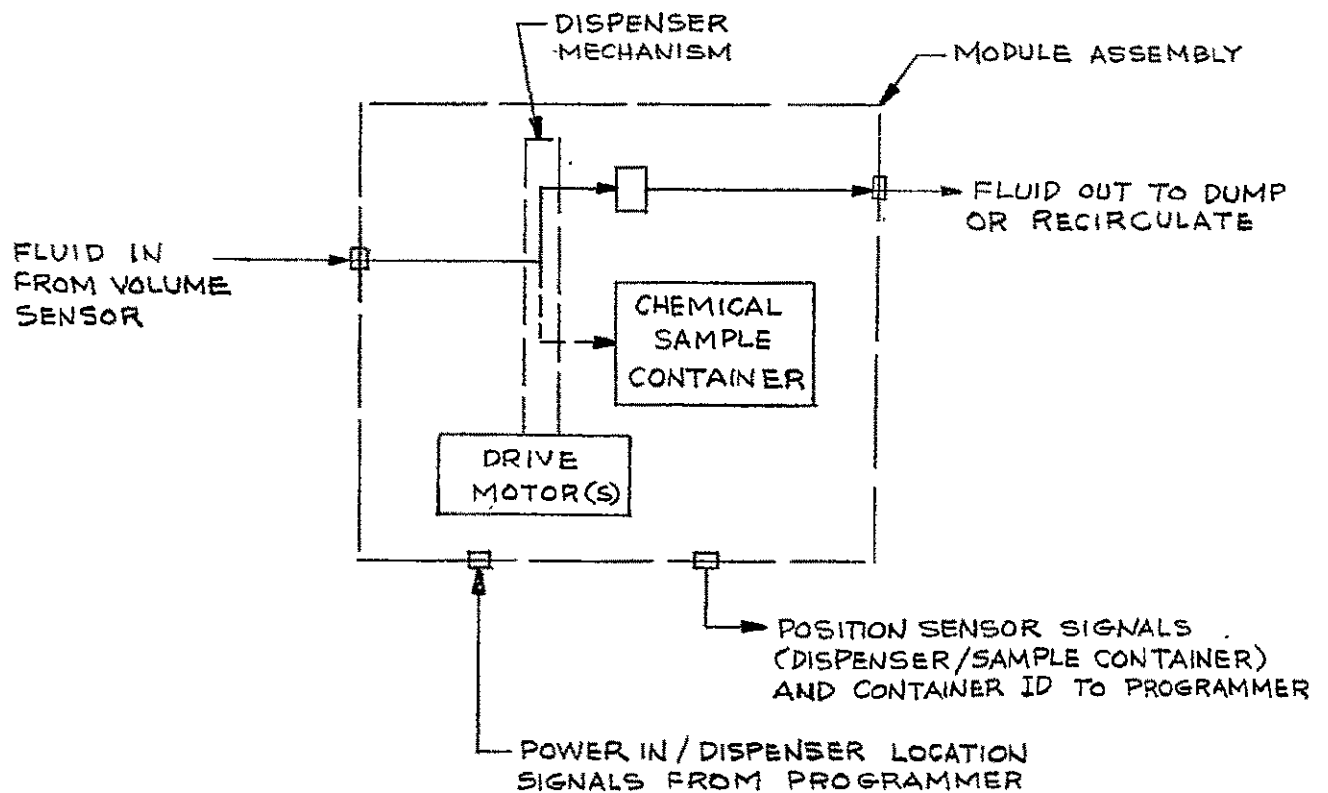


- 20 ml CHEMICAL SAMPLE (USER OPTION)
- LIMITED TO ONE USER (CROSS-CONTAMINATION FROM SAMPLE TO SAMPLE EXCEEDS 0.5 ml)
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>SAMPLE CONTAINER</u>
WEIGHT	1.05 LBS.	0.08 LBS. (EACH)
POWER	7.0 WATTS	N/A

- DERIVED FROM FVMS BREADBOARD PROGRAM

Figure 3-24 BMS Urine Sampling Module - Option No. 2

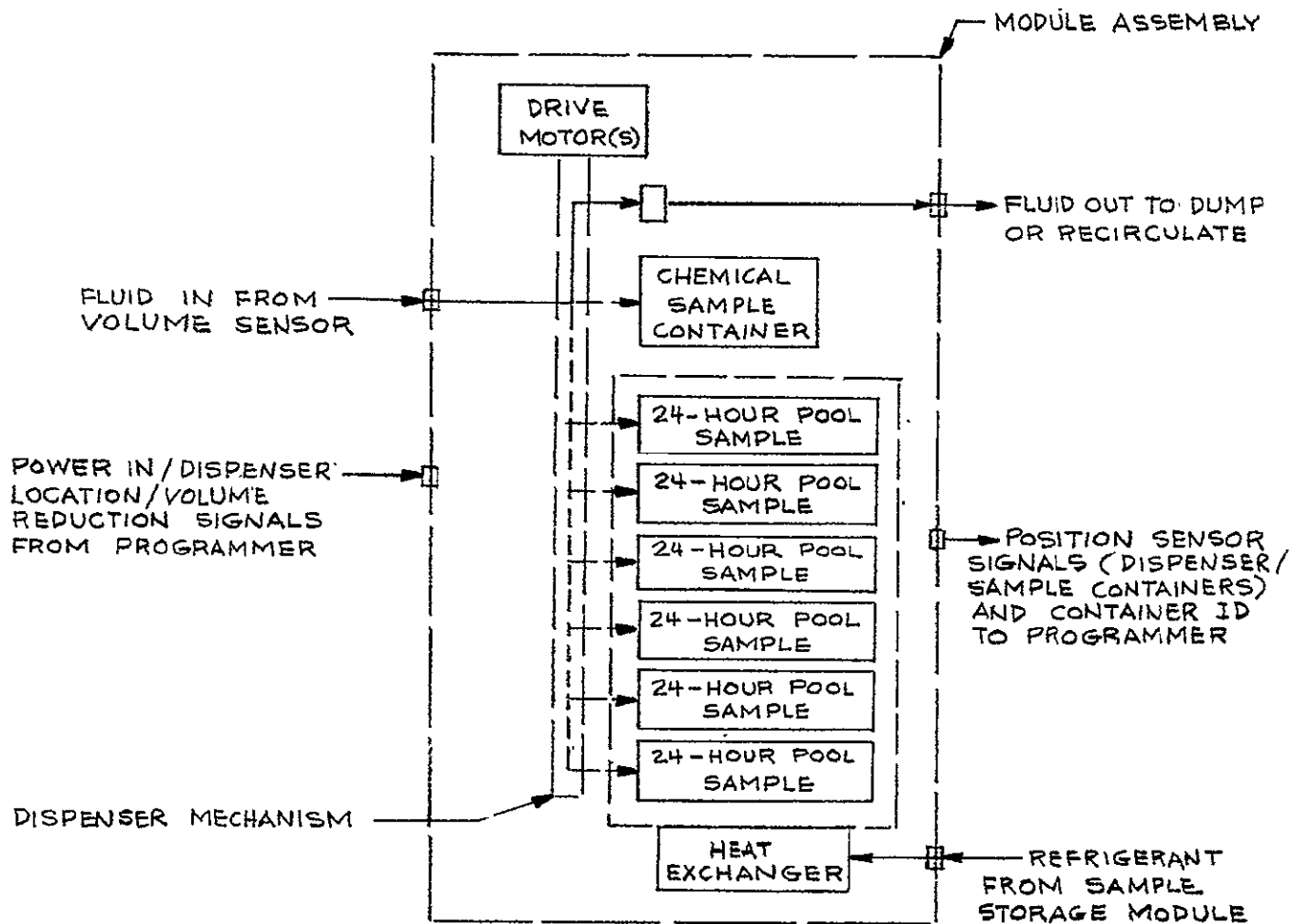


- 5 ml CHEMICAL SAMPLE (USER OPTION)
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>SAMPLE CONTAINER</u>
WEIGHT	3.20 LBS.	0.05 LBS. (EACH)
POWER	11.0 WATTS (PEAK)	N/A

- DERIVED FROM ABSS PROGRAM
- FLUSH CAPABILITY PROVIDED FOR MULTIPLE USERS

Figure 3-25 BMS Urine Sampling Module - Option No. 3

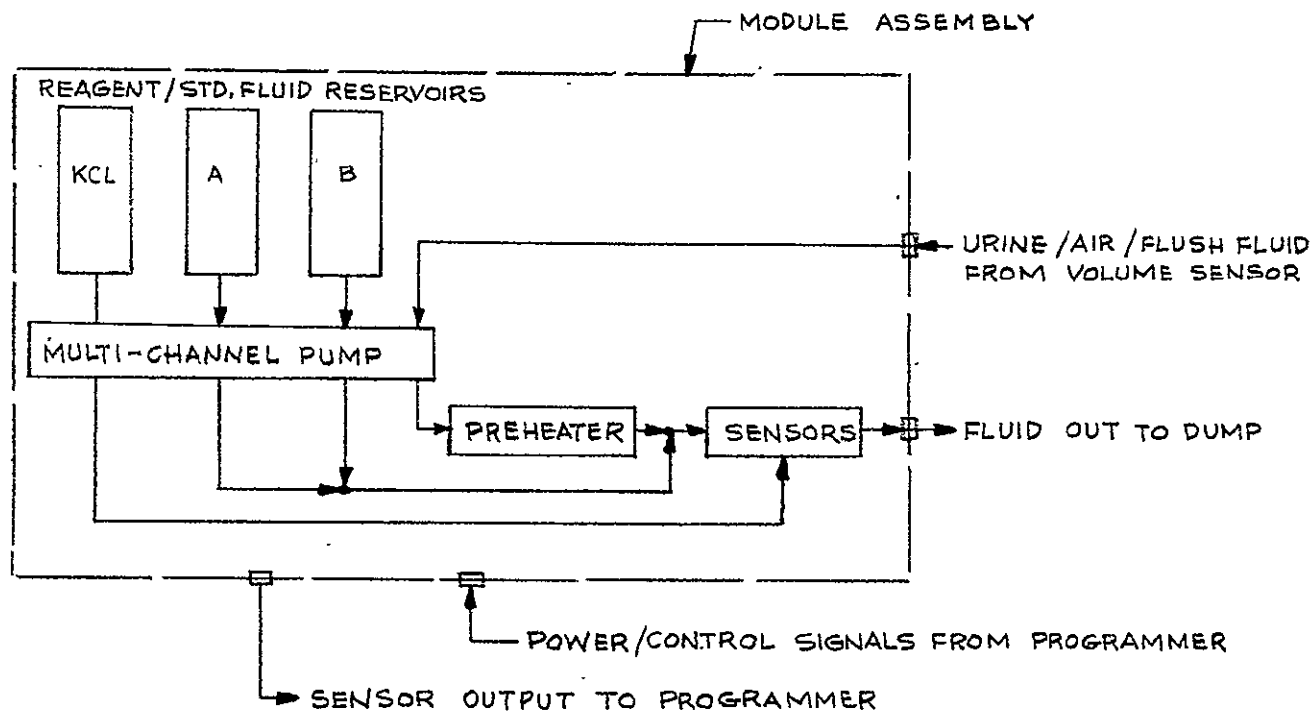


- 5 ml CHEMICAL SAMPLE (USER OPTION)
- REFRIGERATED 24-HOUR POOL SAMPLES (4°C)
- IN PLACE AUTOMATIC VOLUME REDUCTION
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>SAMPLE CONTAINER(S)</u>
WEIGHT	11.2 LBS.	0.06 LBS. (EACH)
POWER	11.0 WATTS PEAK	N/A

- DERIVED FROM ABSS PROGRAM
- FLUSH CAPABILITY PROVIDED FOR MULTIPLE USERS

Figure 3-26 BMS Urine Sampling Module - Option No. 4



- 3 SENSOR ELECTRODE ASSEMBLIES

Na^+ , K^+

Ca^{++} , pH

Cl^-

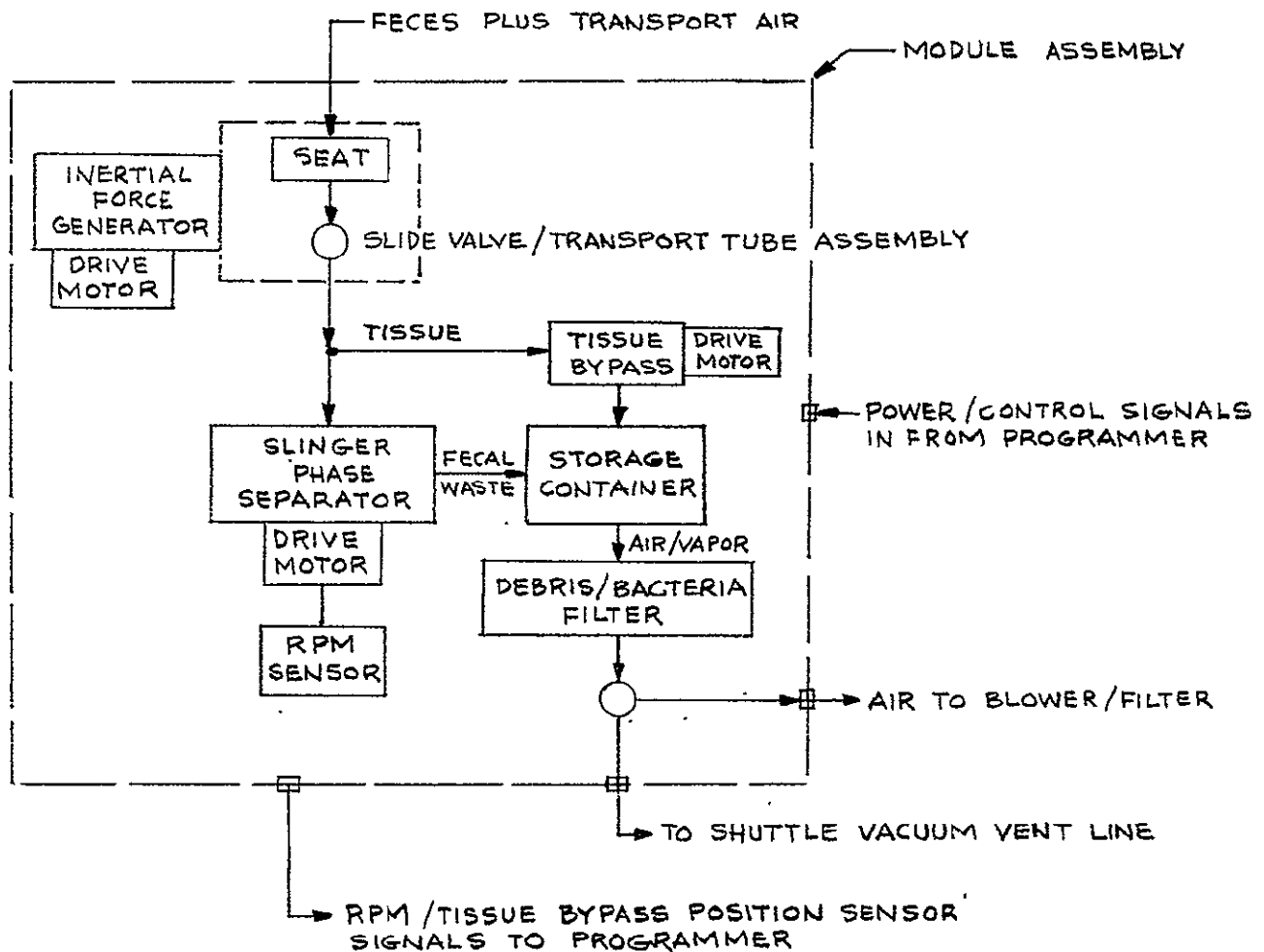
- 2 STANDARDIZATION SOLUTIONS; CALIBRATE BEFORE EACH MEASUREMENT

- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>EXPENDABLES</u>
WEIGHT	33.0 LBS.	21 LBS.
POWER	20.0 WATTS (PEAK)	N/A

- DERIVED FROM AUTOMATED POTENTIOMETRIC ELECTROLYTE ANALYSIS SYSTEM (ORION RESEARCH INC.); DROP pCO_2 , $^{\circ}\text{C}$ AND Ca^{++} CAPABILITY.

Figure 3-27 BMS Urine Analyzer Module

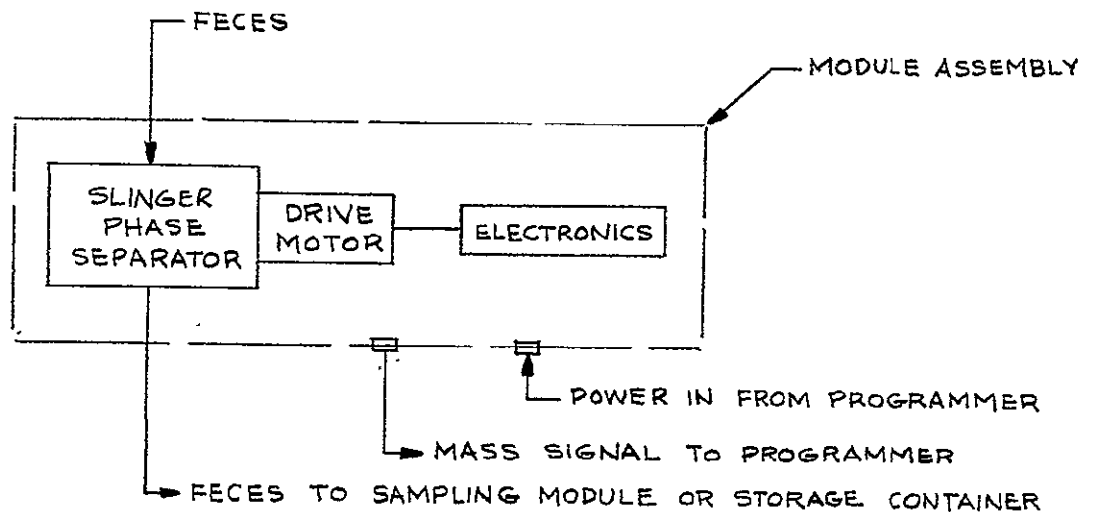


- RPM SENSOR PROVIDES MALFUNCTION ALARM
- INERTIAL FORCE GENERATOR FOR POSITIVE USER/FECES DISENGAGEMENT (ALT.)
- SLINGER PHASE SEPARATOR/DRIVE MOTOR ASSEMBLY ALSO SENSOR FOR FECES MASS MEASUREMENT MODULE
- FECAL WASTE DEACTIVATION VIA VACUUM DRYING
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>EXPENDABLES</u>
WEIGHT	40.3 LBS.	3.0 LBS. (180 MAN DAYS)
POWER	33.0 WATTS (PEAK)	N/A

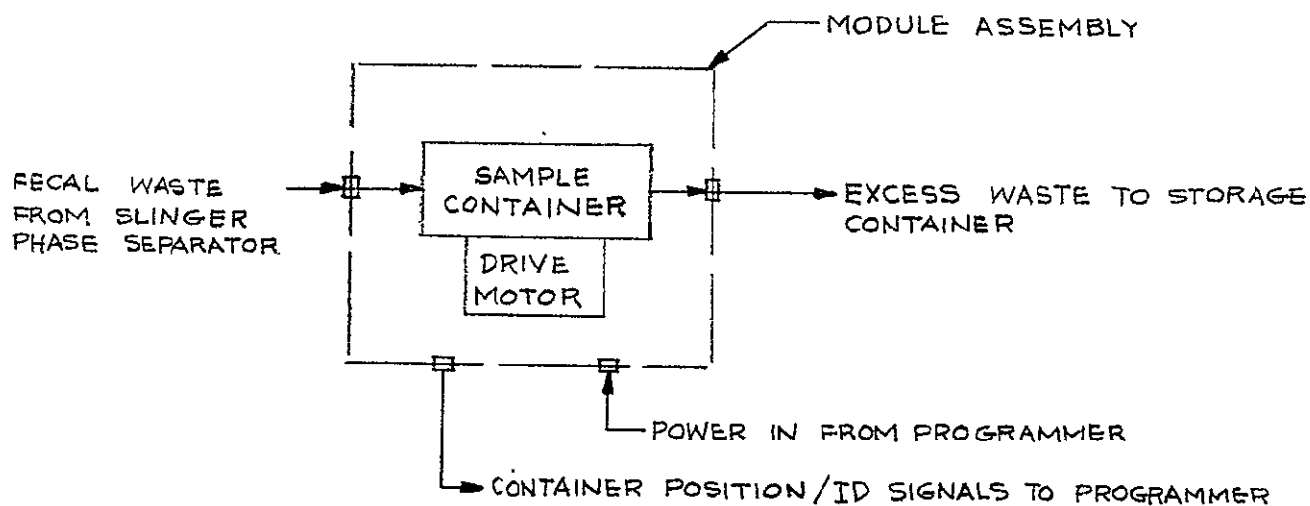
- DERIVED FROM ABSS PROGRAM

Figure 3-28 BMS Feces Collection Module



- ADD ELECTRONICS; SLINGER PHASE SEPARATOR/DRIVE MOTOR COMMON WITH COLLECTION MODULE
 - OPERATION AT USER OPTION
 - NO INTERFERENCE WITH SAMPLING
 - ESTIMATED (FLIGHT SYSTEM, ADDED ELECTRONICS ONLY)
- | | |
|--------|-----------|
| WEIGHT | 0.5 LBS. |
| POWER | 5.0 WATTS |
- DERIVED FROM ABSS PROGRAM

Figure 3-29 BMS Feces Mass Measurement Module

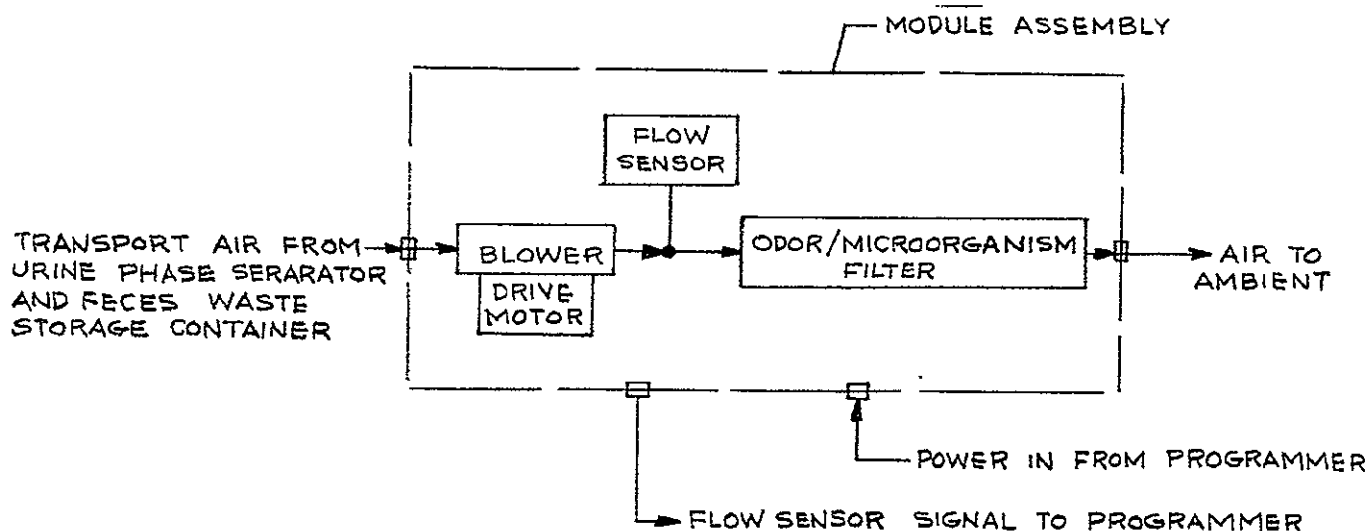


- SAMPLE SIZE 20% TOTAL DEFECATION
- SELF CLOSING SAMPLE CONTAINER
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>SAMPLE CONTAINER</u>
WEIGHT	3.0 LBS.	0.10 LBS. (EACH)
POWER	11.0 WATTS (PEAK)	N/A

- DERIVED FROM ABSS PROGRAM

Figure 3-30 BMS Feces Sampling Module



- FLOW SENSOR PROVIDES MALFUNCTION ALARM
- 8 CFM FLOW FOR URINE COLLECTION
- 30 CFM FLOW FOR FECES COLLECTION (1)
- 0.5 CFM CONTINUOUS FLOW FOR ODOR CONTROL (OPTIONAL; IN LIEU OF FLUID FLUSH AND NO URINE SAMPLING REQUIREMENT)
- ESTIMATED (FLIGHT DESIGN).

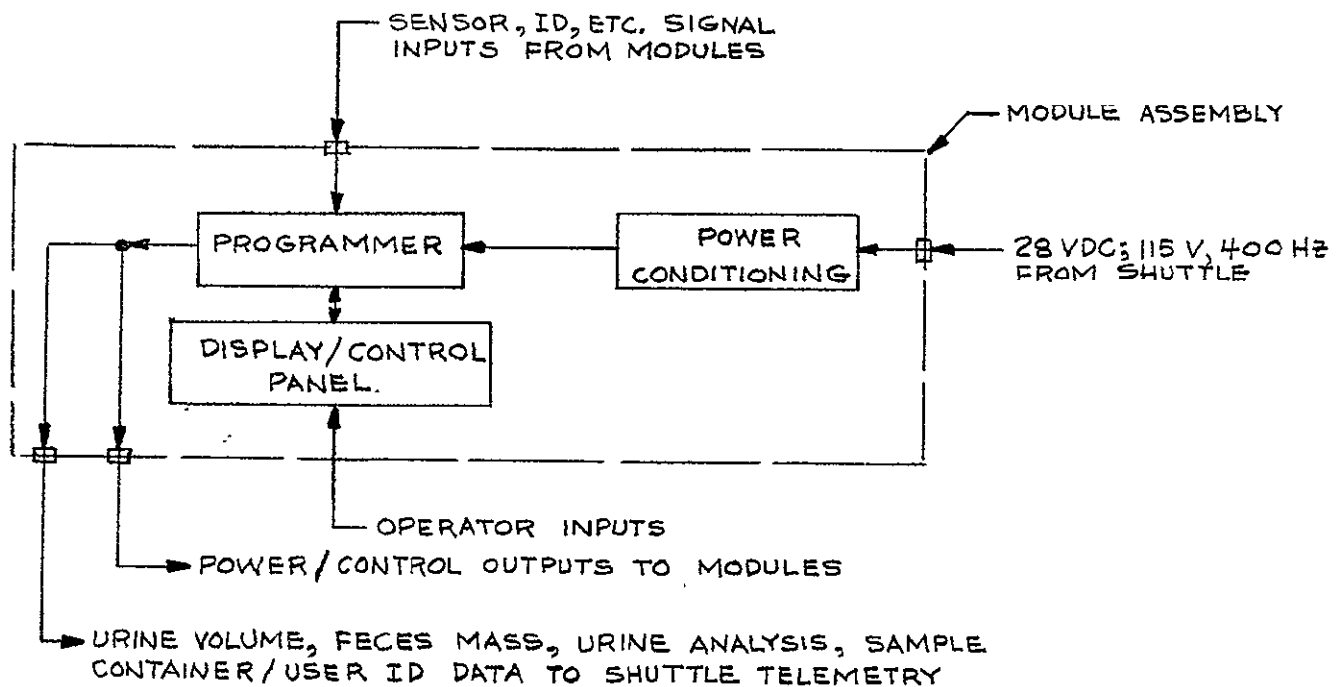
WEIGHT 14.65 LBS.
 POWER 100.0 WATTS (PEAK) (2)

- DERIVED FROM ABSS PROGRAM/ZERO "g" A/C TEST PROGRAM

(1) REDUCE TO 10 CFM IF USE INERTIAL TYPE COLLECTION

(2) 80 WATTS IF URINE COLLECTION ONLY

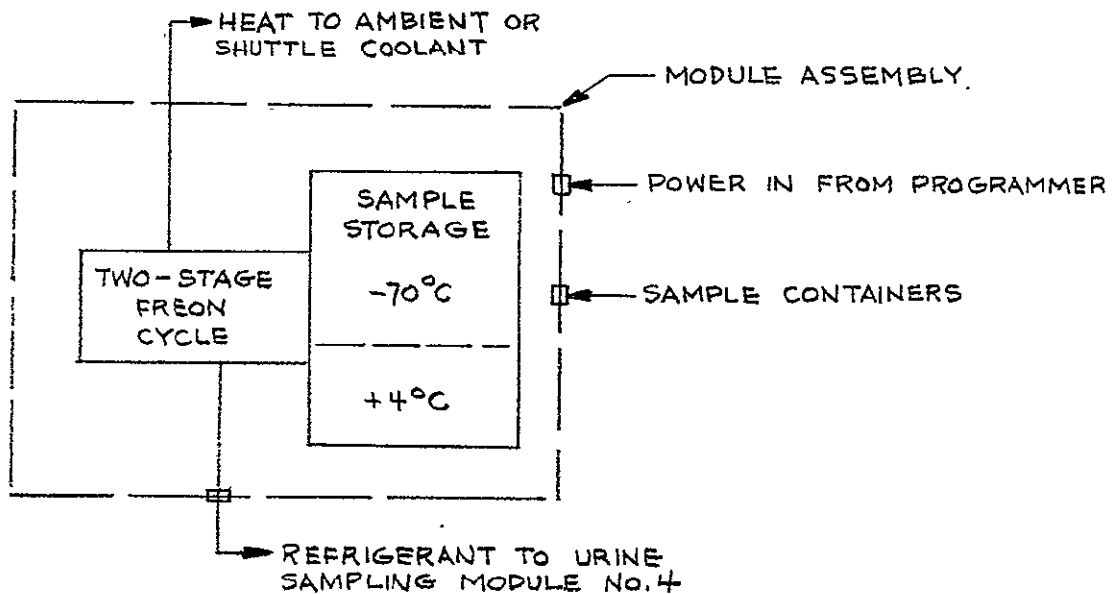
Figure 3-31 BMS Blower/Filter Module



- HARDWARE FOR TOTAL CAPABILITY
 - PROGRAMMABLE FOR SPECIFIC MISSION VIA PROMS (1)
 - STATUS DISPLAYS
 - ESTIMATED (FLIGHT DESIGN)
- | | |
|--------|------------|
| WEIGHT | 4.6 LBS. |
| POWER | 10.0 WATTS |
- DERIVED FROM ABSS PROGRAM

(1) PROGRAMMABLE READ ONLY MEMORY

Figure 3-32 BMS Display/Control Module

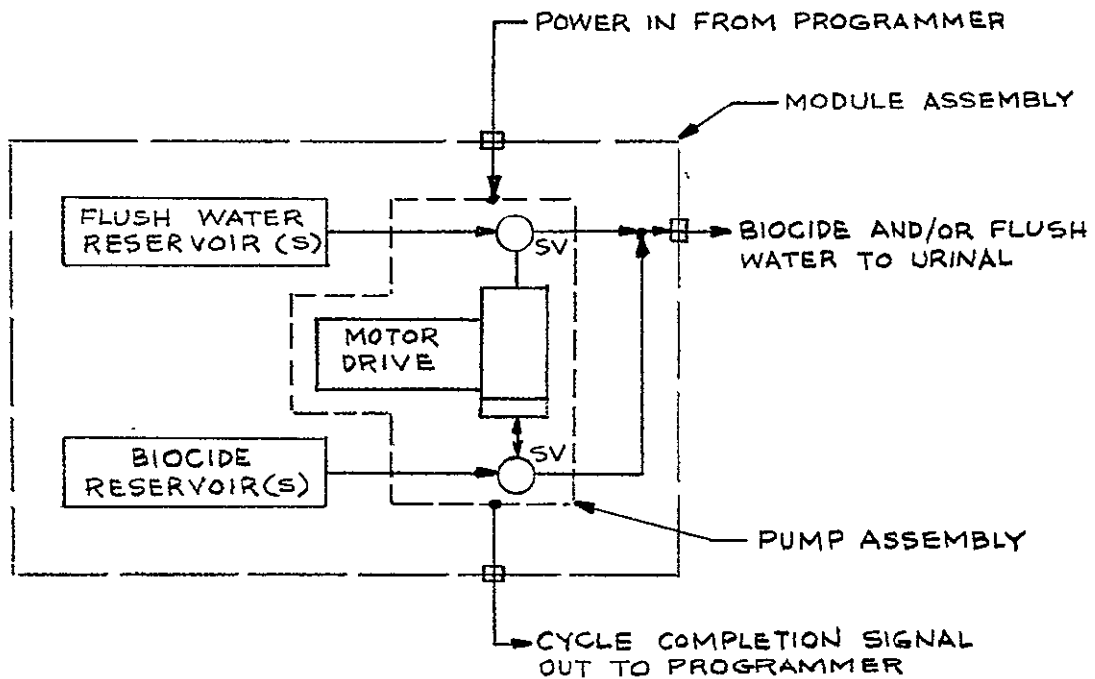


- PROVIDE AS TWO IDENTICAL UNITS WITH 6 FT³ STORAGE CAPACITY EACH
- INTERNAL FORCED AIR CIRCULATION (THERMOSTAT CONTROLLED)
- POTENTIAL SAFETY PROBLEM (FREON + CATALYTIC BURNER → PHOSGENE)(4)
- ESTIMATED (FLIGHT DESIGN)

WEIGHT	128 LBS.
POWER	355 WATTS CONTINUOUS (1) (2) (3).

- (1) INCLUDES COOLING FOR URINE SAMPLING MODULE NO. 4
- (2) 303 WATTS IF STORAGE AREAS AT -20°C AND -70°C.
- (3) MAY NOT BE COMPATIBLE WITH SHUTTLE.
- (4) CATALYTIC BURNER NOT USED ON SHUTTLE.

Figure 3-33 BMS Sample Storage Module

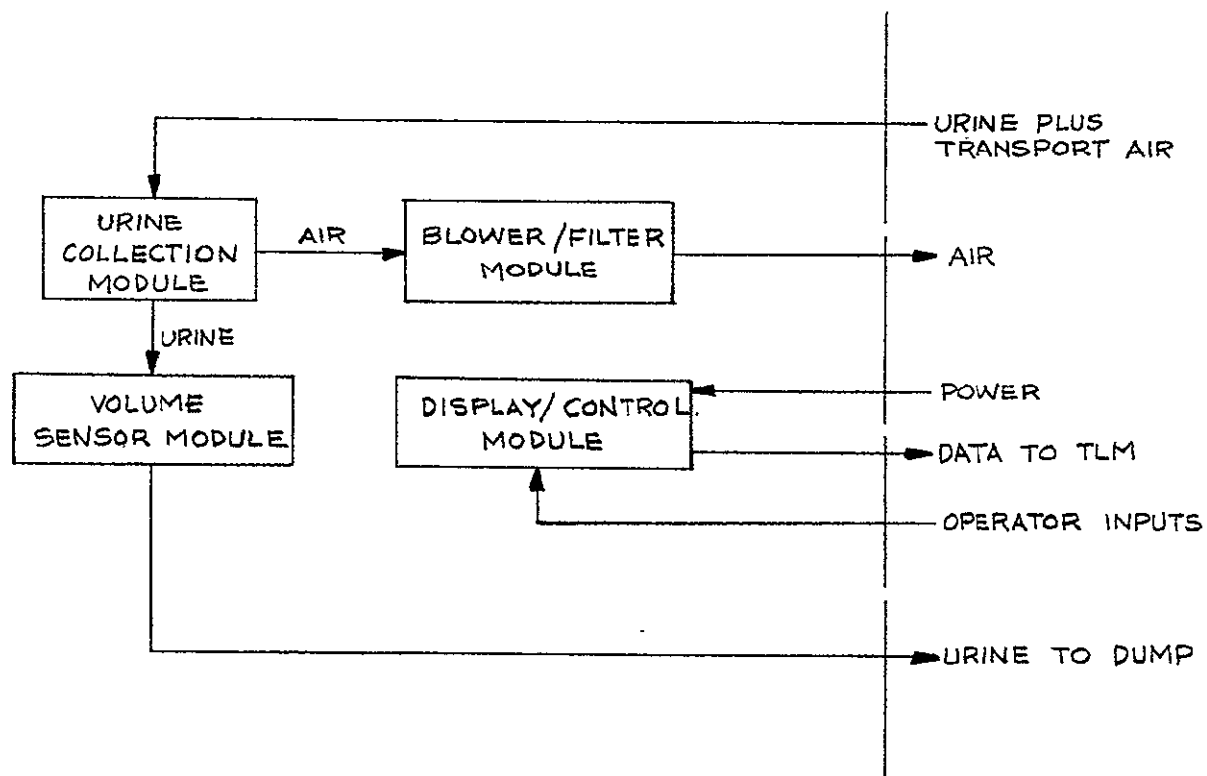


- PUMP ASSEMBLY IDENTICAL TO VOLUME SENSOR ASSEMBLY
- RATIO FLUSH WATER TO BIOCIDES FIXED BY PUMP GEOMETRY
- EXPANDED BLADDER TYPE RESERVOIRS
- MULTIPLE RESERVOIRS (FOUR EACH)
- ESTIMATED (FLIGHT DESIGN)

	<u>MODULE</u>	<u>EXPENDABLES</u>
WEIGHT	38.70 LBS.	198 LBS. WATER; 7.9 LBS. BIOCIDES
POWER	14 WATTS (PEAK)	N/A

- DERIVED FROM ABSS PROGRAM

Figure 3-34 BMS Flush Fluid Module

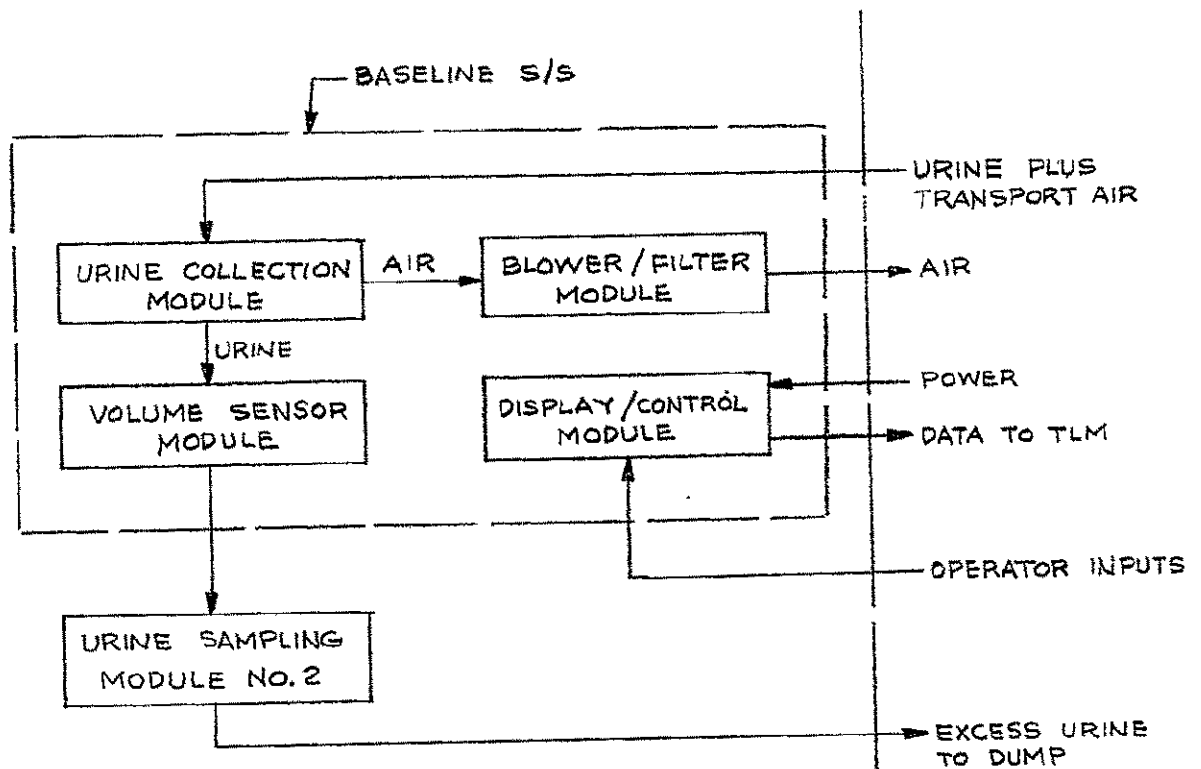


- URINE COLLECTION AND VOLUME MEASUREMENT
- MULTI-SUBJECT USE
- ESTIMATED (FLIGHT DESIGN)

WEIGHT 47.1 LBS. (1)
 POWER 141 WATTS (PEAK)

(1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING

Figure 3-35 BMS Urine Subsystem Baseline

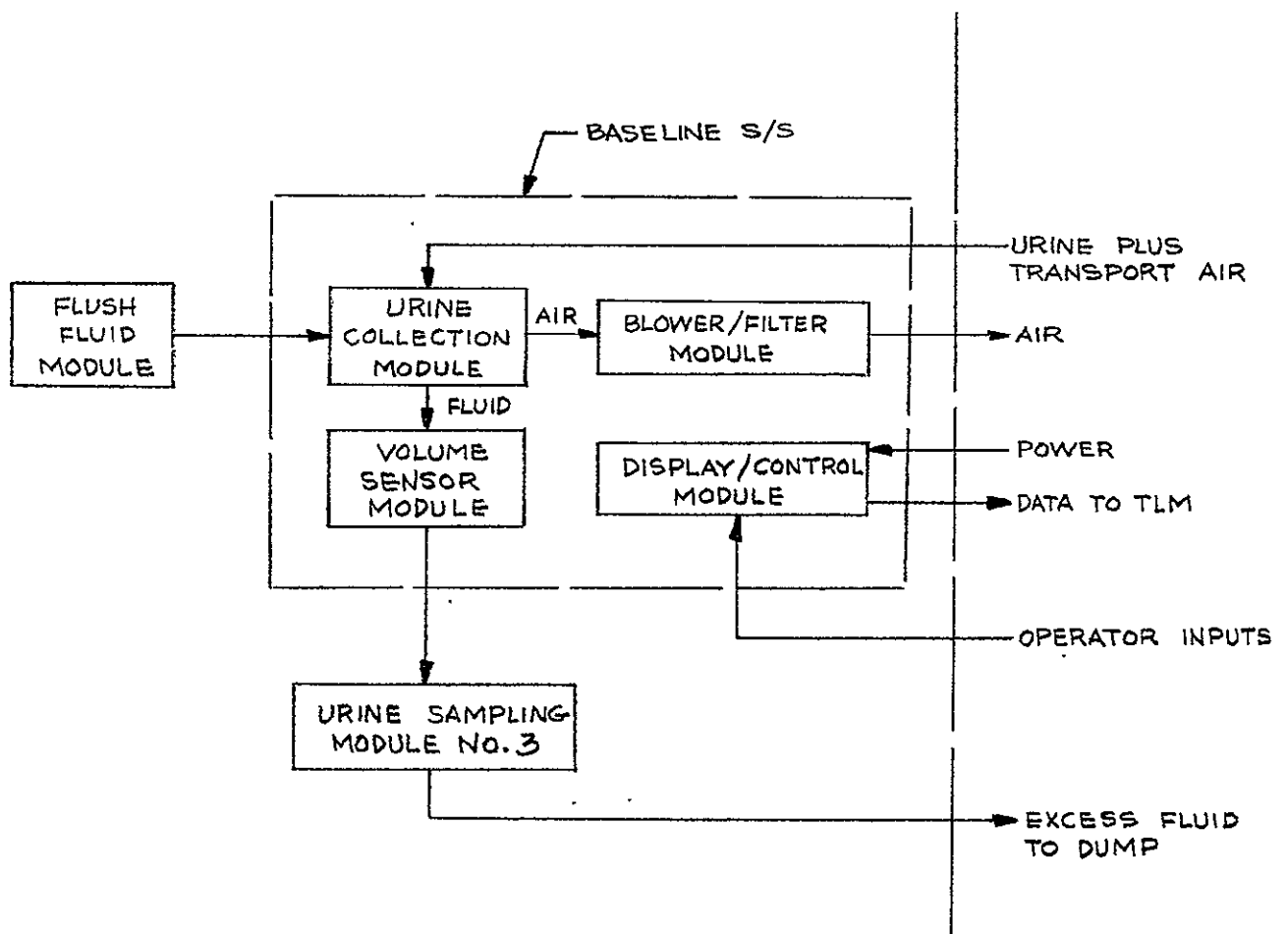


- URINE COLLECTION AND VOLUME MEASUREMENT
- ONE USER LIMIT
- 20 ml CHEMICAL SAMPLE (CHEMICAL STABILIZED)
- ESTIMATED (FLIGHT DESIGN)

WEIGHT 47.2 LBS. (1) PLUS 16.8 LBS. EXPENDABLES (2)
 POWER 141 WATTS (PEAK)

- (1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING
- (2) 210 SAMPLE CONTAINERS

Figure 3-36 BMS Urine Subsystem Baseline Plus - Option 1

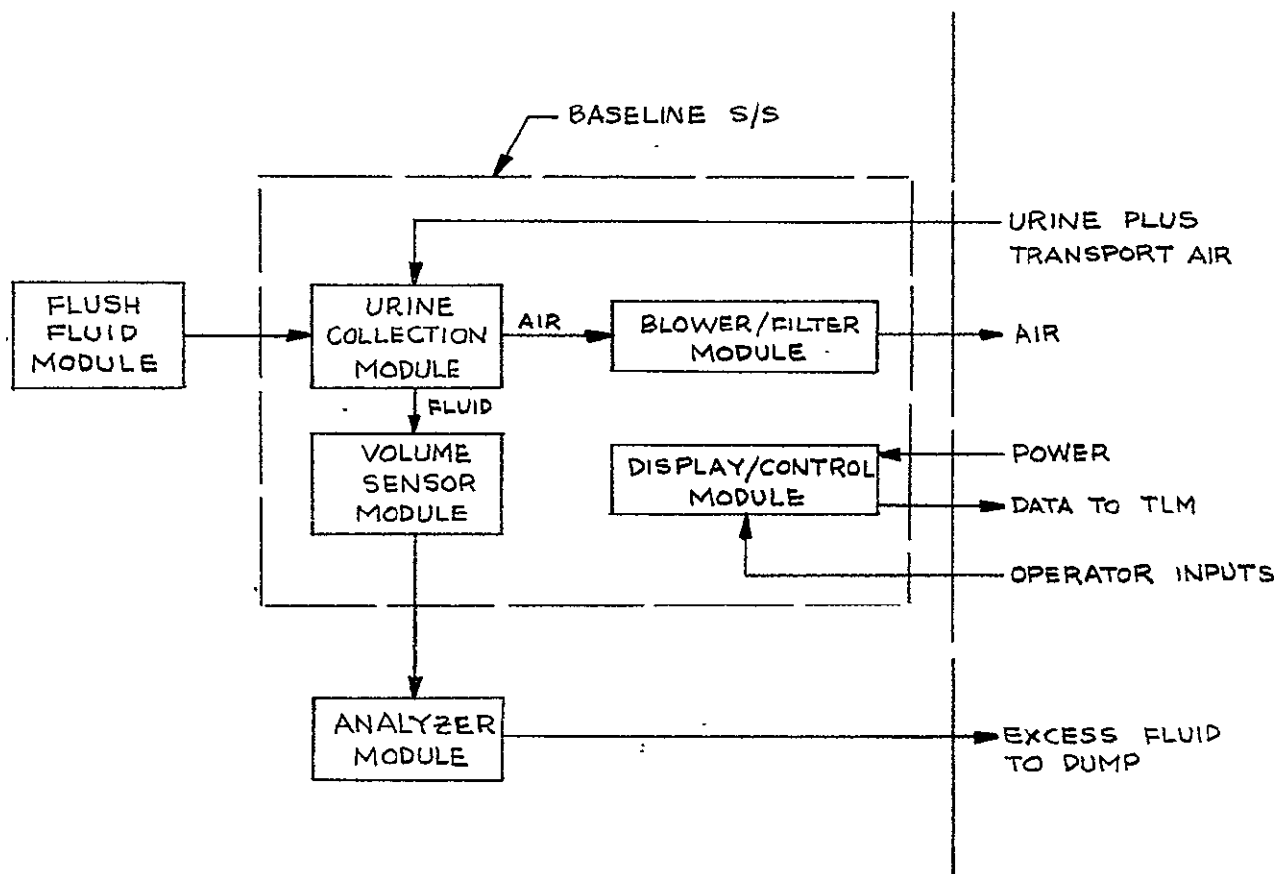


- URINE COLLECTION AND VOLUME MEASUREMENT
- MULTI-SUBJECT USE
- 5 ml CHEMICAL SAMPLE (CHEMICAL STABILIZER)
- ESTIMATED (FLIGHT DESIGN)

WEIGHT 88.0 LBS. (1) PLUS 268.9 LBS. EXPENDABLES (2)
 POWER 141 WATTS (PEAK)

- (1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING
 (2) FLUSH WATER AND BIOCIDES (205.9 LBS.) PLUS 1260 SAMPLE CONTAINERS (63 LBS.)

Figure 3-37 BMS Urine Subsystem Baseline Plus - Option 2



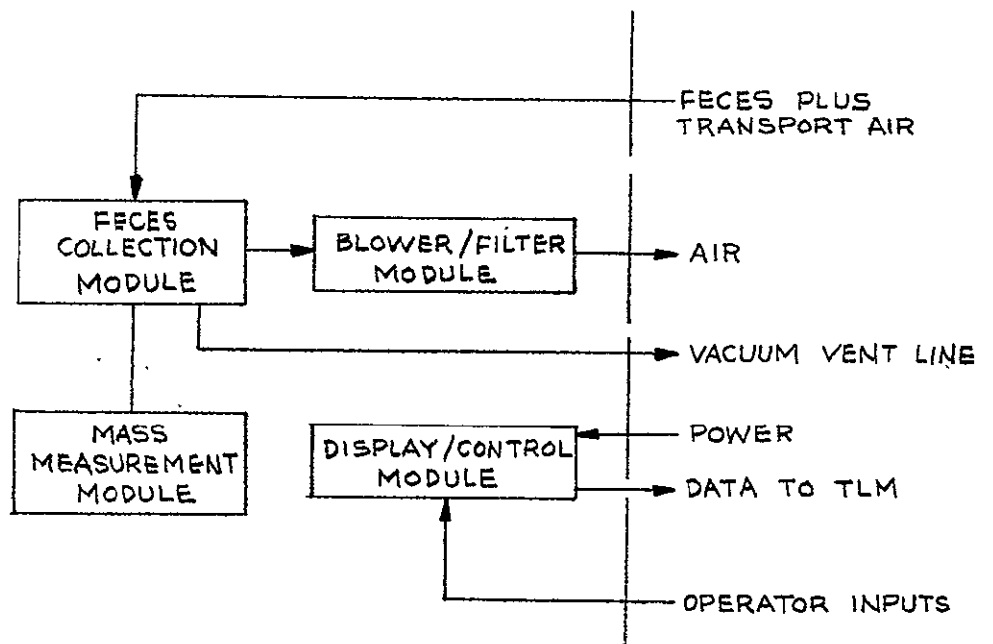
- URINE COLLECTION AND VOLUME MEASUREMENT
- MULTI-SUBJECT USE
- CHEMICAL ANALYSIS (PH AND IONIC).
- ESTIMATED (FLIGHT DESIGN)

WEIGHT 120.8 LBS. (1) PLUS 226.9 LBS. EXPENDABLES (2)
 POWER 141 WATTS (PEAK)

(1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING

(2) FLUSH WATER AND BIOCIDES (205.9 LBS.) PLUS ANALYZER FLUIDS (21 LBS.)

Figure 3-38 BMS Urine Subsystem Baseline Plus - Option 3

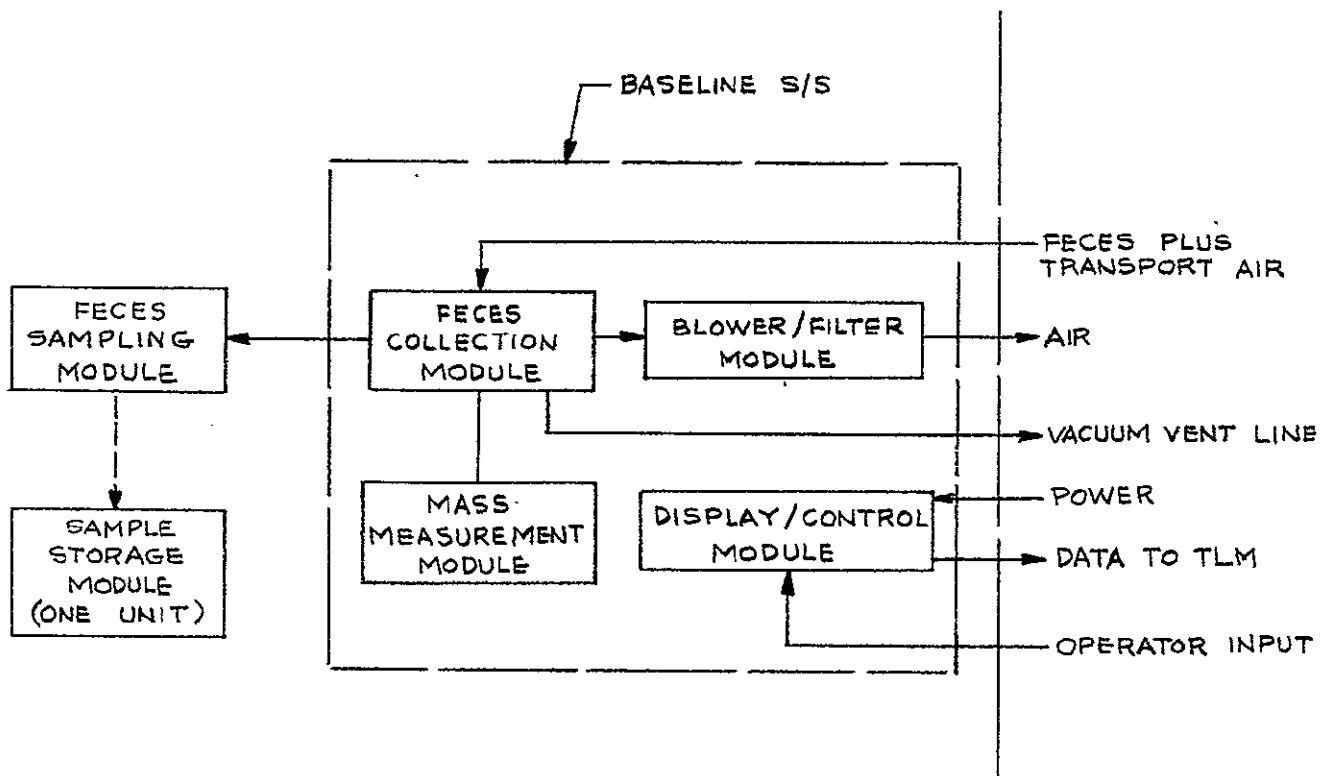


- FECES COLLECTION AND MASS MEASUREMENT
- MULTI-SUBJECT USE
- ESTIMATED (FLIGHT DESIGN)

WEIGHT 54.65 LBS. (1) PLUS 3.0 LBS. EXPENDABLES (2)
 POWER 148.0 WATTS (PEAK)

- (1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING
 (2) TISSUE

Figure 3-40 BMS Feces Subsystem Baseline

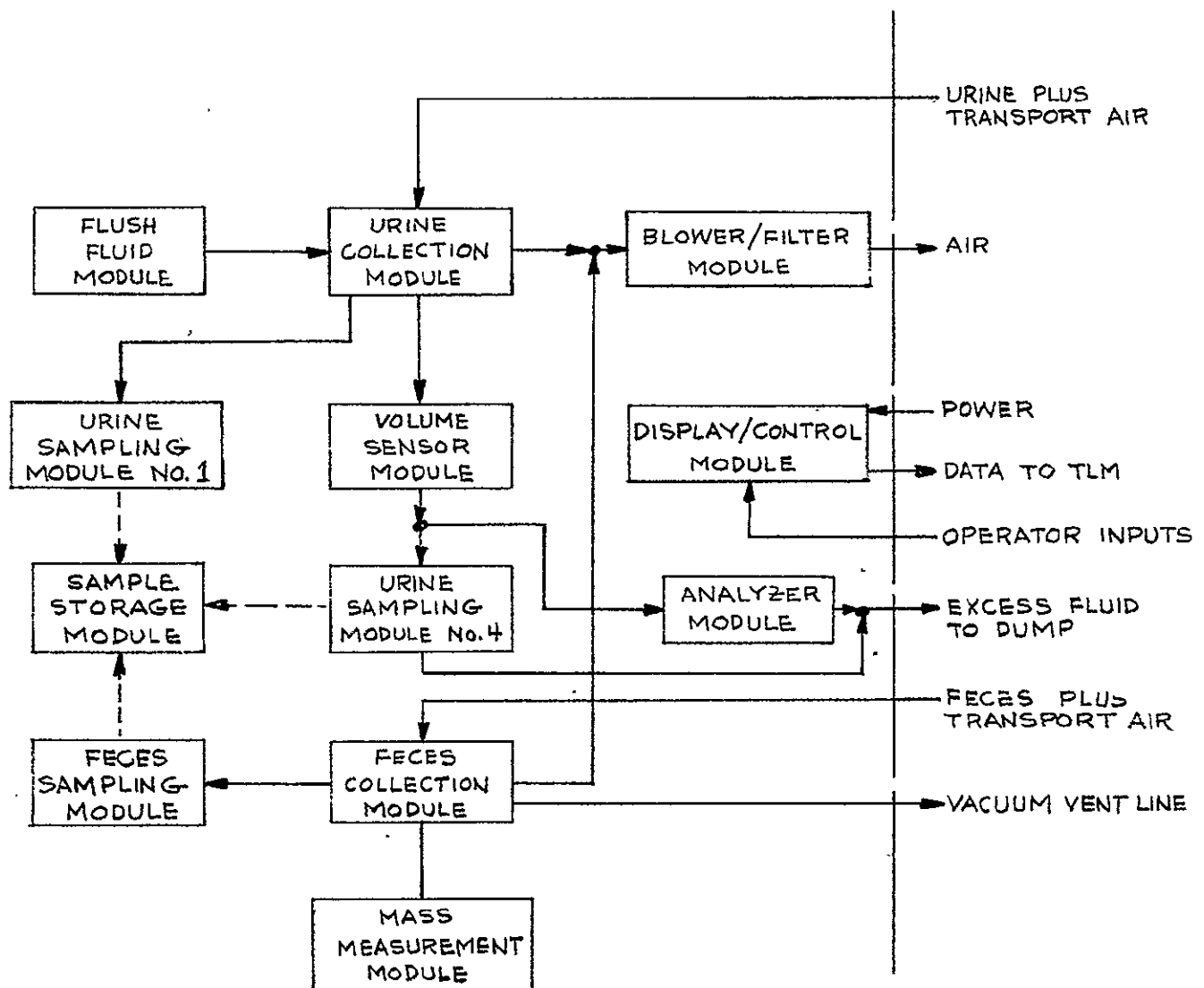


- FECES COLLECTION AND MASS MEASUREMENT
- MULTI-SUBJECT USE
- FECES SAMPLING (20% OF EACH DISCHARGE)
- REFRIGERATED SAMPLE STORAGE
- ESTIMATED (FLIGHT DESIGN)

WEIGHT 122 LBS. (1) PLUS 18 LBS. EXPENDABLES (2)
 POWER 333 WATTS (PEAK)

- (1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING
 (2) 180 SAMPLE CONTAINERS

Figure 3-41 BMS Feces Subsystem Baseline Plus - Option 1



- ESTIMATED. (FLIGHT DESIGN)
 - WEIGHT 307 LBS.(1) PLUS 445 LBS. EXPENDABLES(2)
 - POWER 565 WATTS (PEAK)
- (1) INCLUDING SUPPORT STRUCTURE AND INTERCONNECT WIRING AND PLUMBING
- (2) FLUSH WATER AND BIOCID (205.9 LBS.) ANALYZER FLUID (21 LBS), SAMPLE CONTAINERS (214.8 LBS.) AND TISSUE (3.0 LBS.)

Figure 3-42 BMS Total Capability

3.3.3 BMS/WCS Integration

The SHUTTLE Waste Collection System (WCS) provides the urine and feces collection and disposal capability for the SHUTTLE ORBITER. These functions are identical to those performed by the BMS. The WCS, as currently proposed by GE, is shown in figures 3-43 and 3-44. Figure 3-43 shows a mockup of the proposed WCS; figure 3-44 shows the pneumatic flow diagram.

The WCS as presently defined is completely integratable into the BMS, see Table 3-12. With minor exception, the basic hardware elements are identical for both applications. Interfacing modifications, to accept the various BMS sampling and measurement modules, will be required.

For most effective integration, the BMS hardware must be installed in the area allocated for the WCS or in an area contiguous thereto. The area presently available for the WCS is barely sufficient with only limited accommodation of additional equipment (BMS modules) possible. As a first cut, the additional of urine volume and feces mass measurement plus feces sampling and (limited) urine sampling may be possible. Sample storage flush fluid and urine analyzer modules, as a minimum, will have to be located outside the present WCS installation area. A reduction in number and size of samples will reduce the sample storage and flush fluid installation volume requirements. A review of sampling requirements is recommended.

In summary, equipment commonality between the WCS and BMS is excellent. However due to the limited space allocated the WCS, a possible installation problem exists for an integrated WCS/BMS assembly.

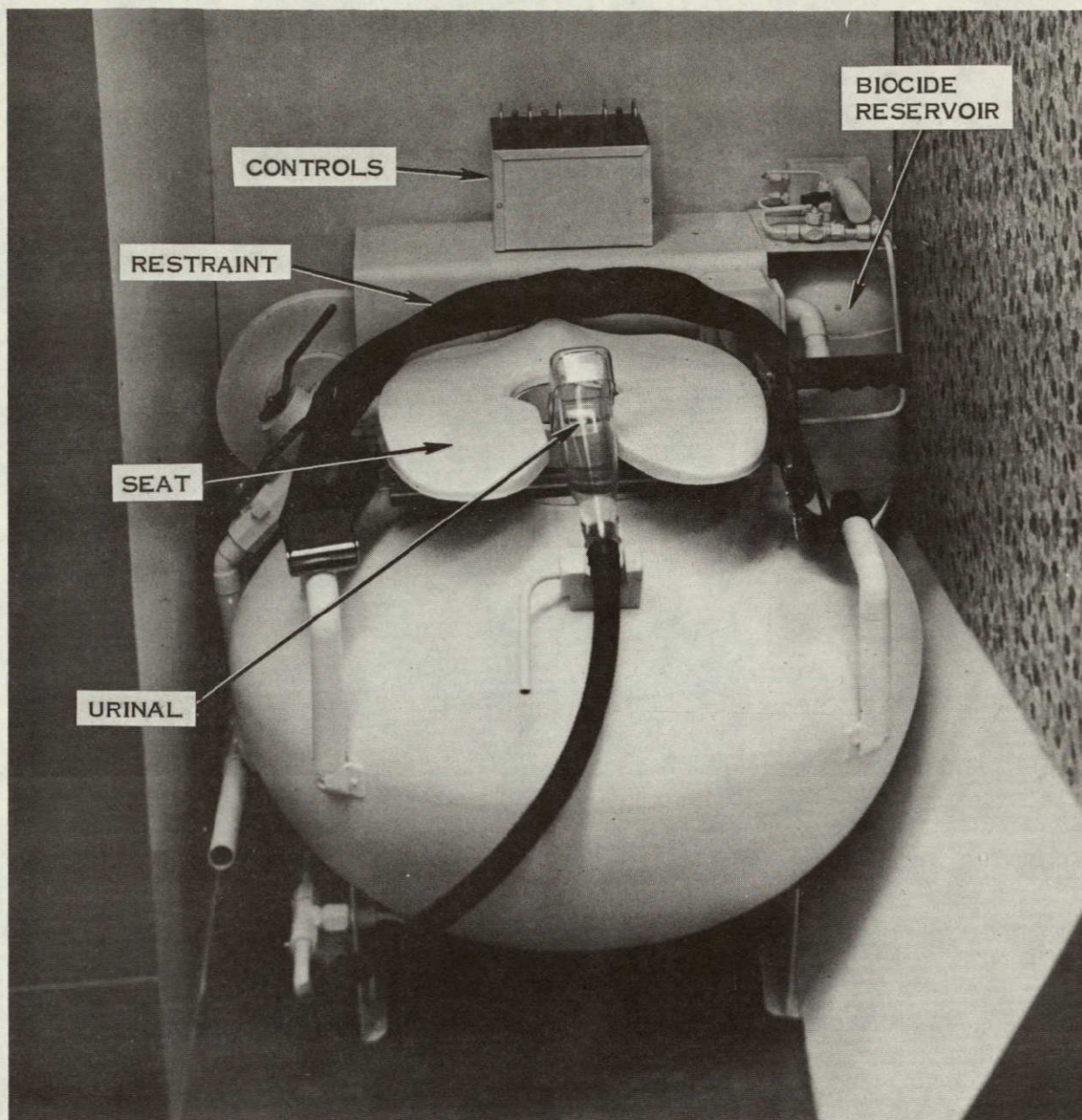


Figure 3-43 WCS Mockup

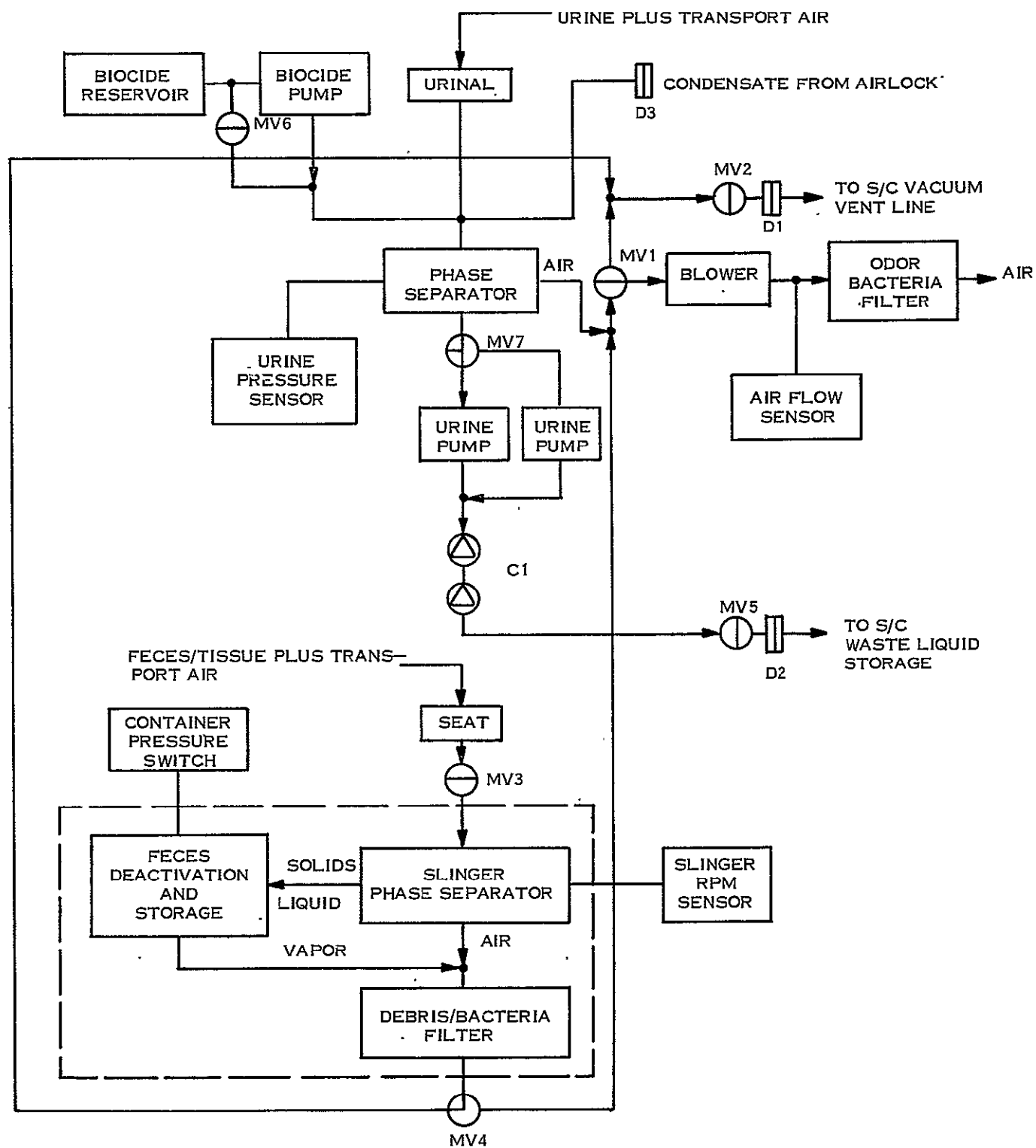


Figure 3-44 WCS Pneumatic Block Diagram

Table 3-12 BMS/WCS Integration

BMS FUNCTIONS	COMPONENTS SIMILAR/ SAME AS WCS ¹	OPERATING MODE SAME AS WCS ¹
URINE COLLECTION/PHASE SEPARATOR	YES	NO ²
URINE VOLUME MEASUREMENT	N/A	N/A
URINE SAMPLING	N/A	N/A
URINE CHEMICAL ANALYSIS	N/A	N/A
FECES COLLECTION/PHASE SEPARATOR/ STORAGE	YES	YES
FECES MASS MEASUREMENT	N/A	N/A
FECES SAMPLING	N/A	N/A
SAMPLE STORAGE	N/A	N/A
AIR FLOW/MICROORGANISM CONTROL	YES	YES
FLUSH FLUID	N/A	N/A
DISPLAY/CONTROLS	NO	NO

¹ IF WCS SPECIFICATION REQUIRES.

² 75 ML PHASE SEPARATOR RESIDUAL USED TO PREVENT AIR TRANSPORT TO S/C WASTE LIQUID STORAGE TANKS. ECS CONDENSATE PHASE SEPARATOR IS POSSIBLE SUBSTITUTE BUT WOULD PREVENT USE OF CONDENSATE AS FLUSH FLUID.

4.0 APPENDIX

4.1 BMS Performance Specification.

4.2 Geoscience Ltd. Report No. GLM-137, Design Modification Study of the Urine Flow Sensor and Electronics Package for SHUTTLE Application.

SPECIFICATION NO. TBD

August 1974

MODULAR BIOWASTE MONITORING SYSTEM

PERFORMANCE
SPECIFICATION

Contract NAS9- 13748

Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Spacecraft Center
Houston, Texas 77058

General Electric Company

MODULAR BIOWASTE MONITORING SYSTEM

PERFORMANCE SPECIFICATION

1.0 SCOPE

This specification defines and establishes the performance requirements for the Modular Biowaste Monitoring System.

1.1 Purpose

The purpose of the Modular Biowaste Monitoring System shall be to provide a modularized hardware assembly applicable to the SHUTTLE ORBITER which, in whole or in part, automatically provides for the collection, storage, volume/-mass measurement and sampling of urine and feces, and the chemical analysis of urine.

1.2 Definitions

For the purposes of this document, the following definitions and abbreviations shall apply:

Later

2.0 APPLICABLE DOCUMENTS

Statement of Work, Contract NAS 9-13748.

3.0 REQUIREMENTS

3.1 Performance

3.1.1 Functional Requirements

3.1.1.1 Collection Requirements

3.1.1.1.1 Urine

The Modular Biowaste Monitoring System shall collect the total quantity of urine voided by a human subject. Specifically, the system shall have the

capability to handle the following urine input volumes and flow rates.

- a. Average output of 2000 ml/man/24 hours
- b. Maximum output of 4000 ml/man/24 hours
- c. Minimum output of 600 ml/man/24 hours
- d. Maximum output of 18,000 ml/6 men/24 hours
- e. Minimum output of 5000 ml/6 men/24 hours
- f. Maximum delivery rate shall be 25 ml/second
- g. Maximum single micturition of 1000 ml
- h. Minimum single void of 35 ml
- i. Average of 7 micturitions/man, 24 hours
- j. Minimum of 5 micturitions/man/24 hours
- k. Maximum of 10 micturitions/man/24 hours
- l. Minimum of 30 micturitions/6 men/24 hours
- m. Maximum of 54 micturitions/6 men/24 hours

3.1.1.1.2 Feces

The Modular Biowaste Monitoring System shall collect the total quantity of feces voided by a human subject. Specific capability requirements are as follows for normal and diarrhetic compositions.

Normal

- a. Average output of 110 grams/man/24 hours.
- b. Maximum output of 500 grams/man/24 hours.
- c. Minimum output of 15 grams/man/24 hours.
- d. Maximum output of 1000 grams/6 men/24 hours.
- e. Minimum output of 300 grams/6 men/24 hours.
- f. Average of 1 defecation/man/24 hours.
- g. Minimum of 3 defecations/6 men/24 hours.
- h. Maximum of 9 defecations/6 men/24 hours.

Diarrhetic (Liquid/Solid Mixture)

- a. Average output of 300 grams/man/discharge.
- b. Maximum output of 500 grams/man/discharge.
- c. Minimum output of 100 grams/man/discharge.
- d. Maximum output of 1200 grams/man/24 hours.
- e. Minimum output of 500 grams/man/24 hours.
- f. Average of 4000 grams/6 men/30 days.
- g. Maximum of 6000 grams/6 men/30 days.
- h. Minimum of 3000 grams/6 men/30 days.

3.1.1.2 Measurement Requirements

3.1.1.2.1 Urine Volume

The Modular Biowaste Monitoring System shall measure the total quantity of urine voided by a human subject. Each micturition volume shall be automatically measured in real time with an error of less than $\pm 2\%$ (2 sigma value).

3.1.1.2.2 Feces Mass

The Modular Biowaste Monitoring System shall measure the total quantity of feces voided by a human subject. Each defecation mass shall be automatically measured in real time with an error of less than $\pm 2\%$ (2 sigma value).

3.1.1.2.3 Urine Chemical Analysis

The Modular Biowaste Monitoring System shall provide a capability for limited automatic real time chemical analysis of individual micturitions. Specific requirements are as follows:

- a. Measure Na^+ , K^+ , Ca^{++} , Cl^- and TBD ionic concentration with an error of less than \pm TBD%.

- b. Measure pH with an error of less than \pm TBD%.

3.1.1.3 Sampling Requirements

The Modular Biowaste Monitoring System shall be capable of automatically providing, at user option, representative samples from each micturition or defecation. Sample containers shall not degrade the sample.

3.1.1.3.1 Urine Micro-organism Sample

The Modular Biowaste Monitoring System shall provide individual user identified sample containers for automatically collecting a nominal 2 ± 1 ml sample from each micturition.

3.1.1.3.2 Urine Chemical Sample

The Modular Biowaste Monitoring System shall provide individual user identified sample containers for automatically collecting a sample from each urination. Sample size shall be adjustable between 5 to 10 ml (± 1 ml).

3.1.1.3.3 Urine 24-Hour Pool Sample

The Modular Biowaste Monitoring System shall provide individual user identified sample containers for automatically collecting a representative 24-hour urine pool sample (adjustable over range of 50 to 110 ml, ± 10 mls) from each user. The total 24-hour pool sample volume shall be controlled within an allowable error of $\pm 2\%$ (2 sigma value). A capability for compensating the 24-hour pool volume for system fluid residual dilution shall also be included.

Micturitions below 50 ml will not contribute to this sample. The 24-hour pool sample volume shall be obtained by directing a nominal 10% of each urination (over 50 ml and separately by subject) into each sample container and at the

end of the 24-hour period reducing the volume to 50 to 110 ± 10 ml. The 24-hour pool sample container shall be located in a refrigerated space held at 5 to 10°C during collection of the sample.

Free gas present in the 24-hour pool samples shall be less than 0.1%.

3.1.1.3.4 Small Micturition Samples

The Modular Biowaste Monitoring System shall collect small micturitions (less than 50 ml) in total.

3.1.1.3.5 Feces Sample

The Modular Biowaste Monitoring System shall provide individual user identified sample containers for automatically and in real time collecting a representative feces sample from each defecation. The sample size shall be a minimum of 20 grams for average and larger discharges and a nominal 20% of the total fecal mass for below average size discharges. Tissue shall be excluded from the sample.

3.1.1.4 Sample Preservation/Storage

The Modular Biowaste Monitoring System shall provide a sample preservation and storage capability which will prevent sample degradation exceeding that compatible with the subsequent post flight sample analyses. Specific requirements shall be as follows:

- a. Urine Micro-organism Sample - Mix with media, integral with each sample container, and store at a nominal 4°C .
- b. Urine Chemical, 24-hour Pool and Small Micturition Samples - Store at a nominal -20 and 70°C .

- c. Urine Chemical Samples - stabilize using a suitable chemical integral with each sample container and store at ambient temperature.
- d. Feces Sample - Store at a nominal -70° C.

3.1.1.5 Disposal Requirements

3.1.1.5.1 Urine

Excess urine shall be automatically transported to the SHUTTLE ORBITER waste liquid storage tanks. A suitable biocide shall be periodically added to the excess urine.

3.1.1.5.2 Feces

Excess feces, both normal and diarrhetic composition and used tissue shall be automatically stored within the Modular Biowaste Monitoring System.

3.1.1.6 Equipment Requirements

The Modular Biowaste Monitoring System shall conform to the functional block diagram of Figure 3.1.-1.

3.1.1.6.1 Collection

The Modular Biowaste Monitoring System collection equipments shall provide for both male and female users. For urine, the collection equipment shall be positionally adjustable to accommodate individual users, including standing or seated position for male users. The system shall be capable of separate or simultaneous collection of urine and feces, at the option of the user. Also the system shall be capable of essentially immediate usage by the next user.

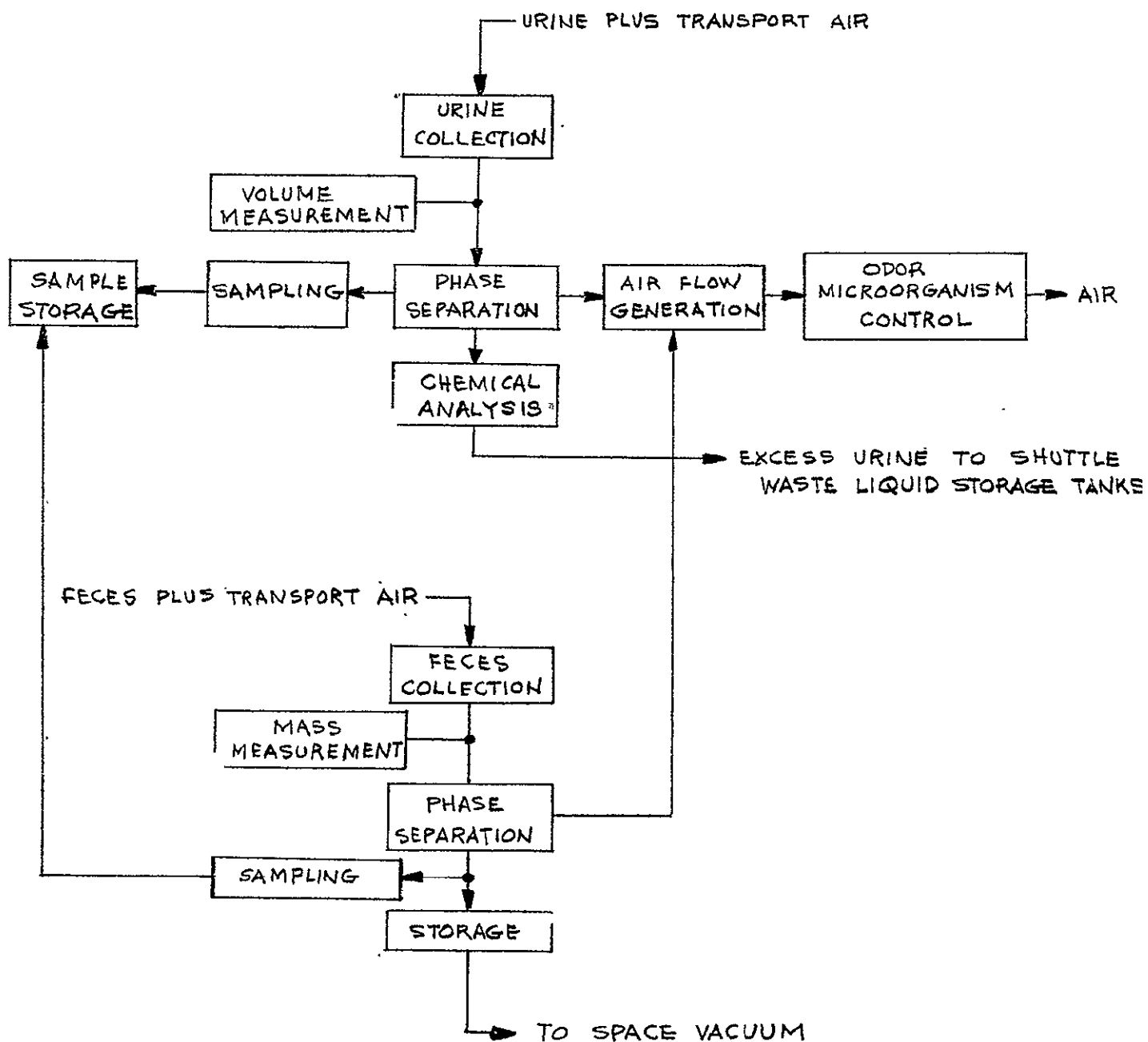


FIGURE 3.1-1 FUNCTIONAL BLOCK DIAGRAM, MODULAR BIOWASTE MONITORING SYSTEM

3.1.1.6.2 Air Transport

The Modular Biowaste Monitoring System shall provide a transport air flow to pneumatically convey urine and feces as part of the collection process. Transport air dumped to the SHUTTLE ORBITER ambient atmosphere shall be subjected to odor and microorganism control.

3.1.1.6.3 Phase Separation

The Modular Biowaste Sampling System shall provide for removal of solid and liquid particles from transport air dumped to the SHUTTLE ORBITER S/C ambient. In addition, the system shall purge urine of free gas bubbles, entrapped within the liquid as part of the collection process, prior to transport to the waste liquid storage tanks. Similarly, fecal particles (liquid or solid) shall be prevented from entering the S/C vent line to space vacuum.

3.1.1.6.4 Disposal

3.1.1.6.4.1 Urine

The Modular Biowaste System shall convey collected urine, after free air removal, to the S/C waste liquid storage tanks. A minimum pressure of 2 psig shall be provided for all flow conditions.

3.1.1.6.4.2 Feces

- a. The Modular Biowaste Sampling System shall be sized to store excess collected feces and used sanitary wipes (quantity as required for the feces and/or urine collection process) for the equivalent of a maximum 180 man-days of usage.
- b. The system shall be designed to provide automatic microorganism control of the stored feces. Vacuum drying shall be used as the control mechanism.

3.1.1.6.5 Operation

The Modular Biowaste Monitoring System shall be designed for automatic operation to minimize user time and chance for operator error. An electronic reset capability shall be provided. Manual control elements shall be easily accessible and positive acting. No waste handling by the user, other than transfer, storage and installation of sample containers, shall be permitted. Maximum delay from completion of defecation and/or micturition until system ready for next user shall not exceed 4 minutes.

3.1.1.6.6 Cross-Contamination

Cross contamination (carryover) from sample to sample shall not exceed a nominal 0.5 grams.

3.1.1.6.7 Power Conditioning

The Modular Biowaste Monitoring System shall be designed to operate effectively on nominal 28 VDC and 115/200 volts, 400 Hz power. Instrumentation shall be powered from the 28 VDC supply; rotating motors from the 400 Hz supply.

3.1.1.6.8 Displays

3.1.1.6.8.1 Status

The Modular Biowaste Monitoring System shall provide a visual indication of operational status.

3.1.1.6.8.2 Data Output

The Modular Biowaste Monitoring System shall provide measurement data correlated with the corresponding mission time, sample container and user identification to the SHUTTLE ORBITER telemetry systems.

3.1.1.6.9 Configuration

3.1.1.6.9.1 Modular Packaging

The Modular Biowaste Monitoring System shall be designed as an integrated system and shall feature modular functional elements. Modular elements shall be selected such that the monitoring capability can be tailored to each specific mission requirements up to the full capability (as specified herein) of the Modular Biowaste Monitoring System.

The selection of specific modular elements shall be based on use frequency, see Table 3.1-1, and commonality of hardware.

3.1.1.6.9.2 Built-In Test Equipment (BITE)

The Modular Biowaste Monitoring System shall include BITE hardware for self monitoring and evaluation of operational status during operation. Discrete status outputs shall be provided to the system status display.

3.1.1.6.10 Safety

3.1.1.6.10.1 Personnel Safety

- a. The safety of the flight and ground personnel shall be a prime consideration in the design of Modular Biowaste Monitoring System hardware. Sharp edges, burrs, corners, and protuberances shall not be permitted. Hardware shall be designed to prevent personal contact with high temperature surfaces (105°F) and hazardous electrical points.
- b. The Modular Biowaste Monitoring System shall be designed to prevent the inadvertent release of collected urine, feces, used tissue and unprocessed transport air into the ambient environment. The inadvertant

Table 3.1-1 Estimated Measurement/Sampling Functions Mission Requirement

Function	Number Missions Required*	Crew Participation
Urine Volume Measurement	75	1 to 6 Men
Urine Sampling		
Microbiological	5	1 to 6 Men
Chemical	20	1 to 6 Men
24-Hour Pool	30	1 to 6 Men
Urine Analysis	15	1 to 6 Men
Feces Mass Measurement	60	1 to 6 Men
Feces Sampling	20	1 to 6 Men

* Based on 100 Mission SHUTTLE ORBITER Program

release requirement shall apply even though the quantities specified in 3.1.1.1.1 and 3.1.1.1.2 are exceeded. Filter (or other hardware) replacement shall be permitted in order to achieve normal operation should the specified quantity limits be exceeded.

3.1.1.6.10.2 Equipment Safety

Modular Biowaste Monitoring System hardware shall have adequate safeguards to prevent hazardous conditions and inadvertent operation; and normal operations, component replacement, the act of replacing components, malfunctions, or failures shall not disable other equipment, personnel, or the flight vehicle.

3.1.1.6.11 Gravity Field Operation

The Modular Biowaste Monitoring System shall be designed to function in either a zero gravity or normal gravity environment.

3.1.2 Operability

3.1.2.1 Useful Life

The Modular Biowaste Monitoring System shall have an operating use life with maintenance, including checkout and in-flight, of 200 hours/mission and 75 missions.

3.1.2.2 Environments

3.1.2.2.1 Storage

The Modular Biowaste Monitoring System shall be capable of meeting the operating performance requirements specified herein after exposure to the following storage condition:

- | | |
|----------------|---|
| a. Temperature | Minus 23 F to plus 150 F. |
| b. Humidity | 0 to 100 percent relative humidity, including conditions wherein condensation takes place in the form of water frost. |
| c. Pressure | Maximum of 15.23 psia (sea level), minimum of 9.76 psia (10,000 feet). |
| d. Ozone | Surface maximum 3 to 6 parts per hundred million (PHM); 35,000 feet maximum 100 PHM. |
| e. Fungus | As specified in MC999-0096. |

3.1.2.2.2 Ground Handling Loads

The Modular Biowaste Monitoring System shall be capable of meeting the operating performance requirements specified herein after exposure to the following ground handling loads when unpackaged.

- | | |
|-------------------|--|
| a. Handling Shock | Bench handling shock as specified in MIL-STD-810. |
| b. Design Shock | 20 g terminal sawtooth shock pulse of a 10 millisecond duration in each of 6 axes. |
| c. Hoisting Loads | 2 g vertical within a plus or minus cone angle of 20 degrees. |

3.1.2.2.3 Flight Environments

The Modular Biowaste Monitoring System shall be capable of operating as specified herein during and after being exposed to any feasible combination of environments as follows:

- | | | | |
|----------------|----------|-------|--|
| a. Temperature | | | |
| Atmospheric | Minimum: | 65 F | |
| | Maximum: | 100 F | |
| Structural | Minimum: | 60 F | |
| | Maximum: | 120 F | |

- b. Pressure, Cabin Maximum: 16.0 psia
 Minimum: 13.75 psia
 Oxygen partial pressure maximum 3.45 psia
 Minimum: 2.75 psia
 Atmosphere Diluent - Nitrogen.
- c. Relative Humidity Maximum: 85 percent
- d. Acceleration Plus or minus 5.0 g.
- e. Vibration
- Mission Phase
- Random vibration occurs at liftoff, transonic, and qmax. Acceleration spectral density increasing at the rate of plus 6 db/octave from 20 to 100 Hz; constant at .15 g²/Hz from 100 to 400 Hz; decreasing at the rate of minus 9 db/octave from 400 to 470; constant at 0.1 g²/Hz from 470 to 800 Hz; decreasing at the rate of minus 6 db/octave from 800 to 2000 Hz.
- Sinusoidal vibration results from wind gusts, engine start and shutdown, staging and landing. Sweeps 5 to 35 Hz at one octave per minute at .25 g's.
- f. Crash Safety Equipment mounting interface shall be designed to withstand terminal peak sawtooth pulses of plus or minus 40 g, 11 milliseconds duration in all axes. There shall be no failure of the mounting attachment, and the equipment shall remain in place and not create a hazard.
- g. Shock
- Landing Rectangular pulses of the following peak accelerations, time durations, and numbers of applications in the vertical/up direction during landing:

<u>Acceleration (g Peak)</u>	<u>Duration (Milliseconds)</u>	<u>Applications</u>
0.23	170	22
0.28	280	37
0.35	330	32
0.43	360	20
0.56	350	9
0.72	320	4
1.50	260	1
		<u>125</u>

3.1.2.2.4 Checkout Environment (Vehicle Installed)

The Modular Biowaste Monitoring System shall be capable of operating as specified herein during and after exposure to environments specified as follows:

a. Pressure

Operational Leak Check

Cabin pressure of 18.0 psia maximum at sea level

Structural

30 psia

b. Temperature, Cabin

35 F minimum, 120 F maximum

c. Humidity

8 to 100 percent relative humidity including conditions wherein condensation takes place in the form of water or frost.

3.2 Interface Requirements

3.2.1 Flight Vehicle

3.2.1.1 Fluid

If require, water and high pressure gas shall be supplied integral to the Modular Biowaste Monitoring system.

3.2.1.1.1 Urine

- a. Urine and other waste liquid shall be disposed of by pumping to the S/C waste liquid storage tanks against a tank back pressure of 2 psig. Air content shall be less than 1.0% by volume.
- b. Urine and other waste liquid may be vented overboard during emergency operation only.

3.2.1.2 Vacuum

Feces vacuum drying shall be accomplished via a connection to the S/C overboard dump vent. Air lost to space shall not exceed 1.0 lbs/day.

3.2.1.3 Electrical

Power 28 VDC or 110/200 volt, 400 Hz (3 phase, 4 wire), shall be supplied to the Modular Biowaste Monitoring System from power outlets located adjacent to the system.

3.2.1.4 Environment Control

- a. Thermal - Modular Biowaste Monitoring System assembly generated heat, not to exceed TBD watts, shall be dissipated to the ambient atmosphere.
- b. The system shall not discharge toxic or noxious gases or vapors or microorganisms to the ambient environment.

3.2.1.5 Controls/Displays

All controls and displays required for Modular Biowaste Monitoring System operation shall be integral with the system hardware assembly.

3.2.1.6 Lighting

The Modular Biowaste Monitoring System shall be designed to be compatible with planned SHUTTLE ORBITER illuminated levels.

3.2.1.7 Data

The Modular Biowaste Monitoring System shall be designed to be compatible with the SHUTTLE ORBITER Telemetry System for recording and/or transmission of measurement and associated data.

3.2.2 Flight Crew Interfaces

- a. The Modular Biowaste Monitoring System shall be designed to accommodate male and female crew members ranging in size from the 40th to 90th percentile.
- b. Urine collection shall be accomplishable in either a "seated or standing" position, at the option of the user.
- c. Urine and feces collection may be accomplished simultaneously or separately at the option of the user.

DESIGN MODIFICATION STUDY OF THE URINE FLOW
SENSOR AND ELECTRONICS PACKAGE
FOR SHUTTLE APPLICATION

for

General Electric Valley Forge
(P.O. 028-P21028)

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July 24, 1974

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I. INTRODUCTION

General Electric has requested Geoscience to perform a design modification study of the urine flow sensor and the associated electronics package for Shuttle application. Specifically, the urine flow rate has been set at 45 cc/sec and the pressure drop through the flow sensor has been limited to 12 inches of water. An air flow rate range of 5 to 15 ft³/minute was to be considered. In addition, a brief review of the electronics package was also to be made so that the system component sizes, weights and power requirements can be approximated at this time.

II. PRESSURE DROP CHARACTERISTICS FOR THE URINE-AIR FLOW THROUGH THE FLOW SENSOR

Because of the higher air flow rate and lower flow sensor pressure drop requirements in the Shuttle application, it is necessary to use a sensor with a larger tube diameter. Brief analytical and experimental pressure drop studies were conducted to verify the modifications needed for the new requirements; the results are given below.

A. Predicted Pressure Drop-Flow Characteristics

The pressure drop-flow characteristics of a two-component, two-phase mixture are complicated by the fact that a number of phase distributions are possible. Such different phase distributions yield different pressure drop functions which are outlined below.*

The frictional, two-phase flow pressure loss in a tube is usually expressed as

$$\left(\frac{\Delta P}{\Delta L}\right)_{\text{TPF}} = \left(\frac{\Delta P}{\Delta L}\right)_g F \quad (1)$$

where

$$\left(\frac{\Delta P}{\Delta L}\right)_{\text{TPF}}, \text{ two phase flow frictional pressure gradient}$$

* It is pointed out that while different phase distributions yield different pressure drop characteristics, the axial fluid and wall temperature gradients in the established flow region of a uniformly heated flow tube do not vary with different phase distributions.

$\left(\frac{\Delta P}{\Delta L}\right)_g$, frictional pressure gradient for gas flow only

F , two-phase flow pressure drop function which includes
all of the system variables

The pressure gradient for gas flowing alone is calculated from the classical Weisbach frictional pressure drop equation.

1. Martinelli Mixed Flow Model

Martinelli's mixed flow model is semi-empirical having no detailed description of the distribution of the two phases.

The functions for Equation 1 for this case follows:

$$F = \phi^2 = F_1(\chi) \quad (2)$$

$$\chi = F_2(\mu_L, \mu_g, \rho_L, \rho_g, \dot{w}_L, \dot{w}_g) \quad (3)$$

2. Separated Flow Model

The Geoscience separated flow model is based on the postulate that the liquid along the tube wall is in the viscous state and that air flows in the core under turbulent conditions.

A fluid flow analysis has previously been performed for this model. The function for Equation 1 for this case follows:

$$F = F_3(\rho_L, \rho_g, \dot{w}_L, \dot{w}_g, r_0, r_1, z, z_p) \quad (4)$$

3. Slug Flow Model

The Geoscience slug flow model is based on the postulate that consecutive slugs of liquid and gas flow through the tube in the turbulent state. A fluid flow analysis of this system has previously been made. The function for Equation 1 for this case follows:

$$F = F_4 \left(\rho_l, \rho_g, y_l, y_g \right) \quad (5)$$

On physical grounds, the slug flow and mixed flow models give greater pressure drop values than the separated flow model.

4. Results

The above equations were evaluated for 1/2 inch and 5/8 inch I.D. tubes with length to diameter ratios of 80; urine flow rates of 45 cc/sec and a range of air flow rates were considered. The results for the 5/8 inch tube are shown in Table I.

B. Two-Phase Flow Pressure Drop Experiments

Two-phase flow pressure drop measurements were made using two horizontal test sections of circular cross section, one straight and the other coiled in a 10.5 inch diameter helix. Both tubes were

TABLE I

Two Phase Air-Water Flow Pressure Drop Predictions for Different
Two Phase Flow Models (for $D = 5/8"$, $L/D = 80$, $\dot{Q}_l = 45$ cc/sec,
 $p = 14.7$ psia)

	\dot{Q}_a	ΔP_a	ΔP_{TF}
	ft ³ /min	psi	psi
Martinelli			
Mixed Flow	5	.031	.496
	10	.103	1.054
	15	.214	1.561
Separated Flow	5	.031	.217
lam. liq. annulus,	10	.103	.618
turb. air core,	15	.214	1.070
$\xi/\xi_p = .15/.03$			
Separated Flow,	5	.031	.046
lam. annulus,	10	.103	.144
turb. core,	15	.214	.257
$\xi/\xi_p = .03/.03$			
Slug Flow	5	.031	.535
	10	.103	.929
	15	.214	1.357

5/8 inch inside diameter and 50 inches long. These test sections were installed in an apparatus shown schematically in Figure 1.

The air flow path through the apparatus contains an air-flow valve, flow mixer tee, the test section with wall pressure taps on either end, a phase separator, air damping tank and nozzle. The water flow enters this path at the mixer tee and leaves it at the phase separator. The air flow is measured with a pitot tube located in the exit plane of a nozzle installed in the air pulsation damping tank. The air tank was necessary to damp out flow pulsations so that the pitot tube pressure would be readable. Two phase flows are quite unsteady, so that the instantaneous values of both the air and water flows at the test section exit can be far from their mean values. The water flows out of a valve below the phase separator, and this valve is not always flooded with water, so some air normally bypasses the air flow metering system. During air flow measurements, the water outlet valve was adjusted to maintain a constant water level above the valve so that air would not be displaced or lost from the water outlet during these measurements.

Fluctuations in the building water supply pressure made variations in the water flow rate intolerable for these experiments. In order to remove the variations, a combination of a booster pump which raises the line pressure to about 125 psig, and a pressure regulator, which maintains its outlet pressure at about 35 psig,

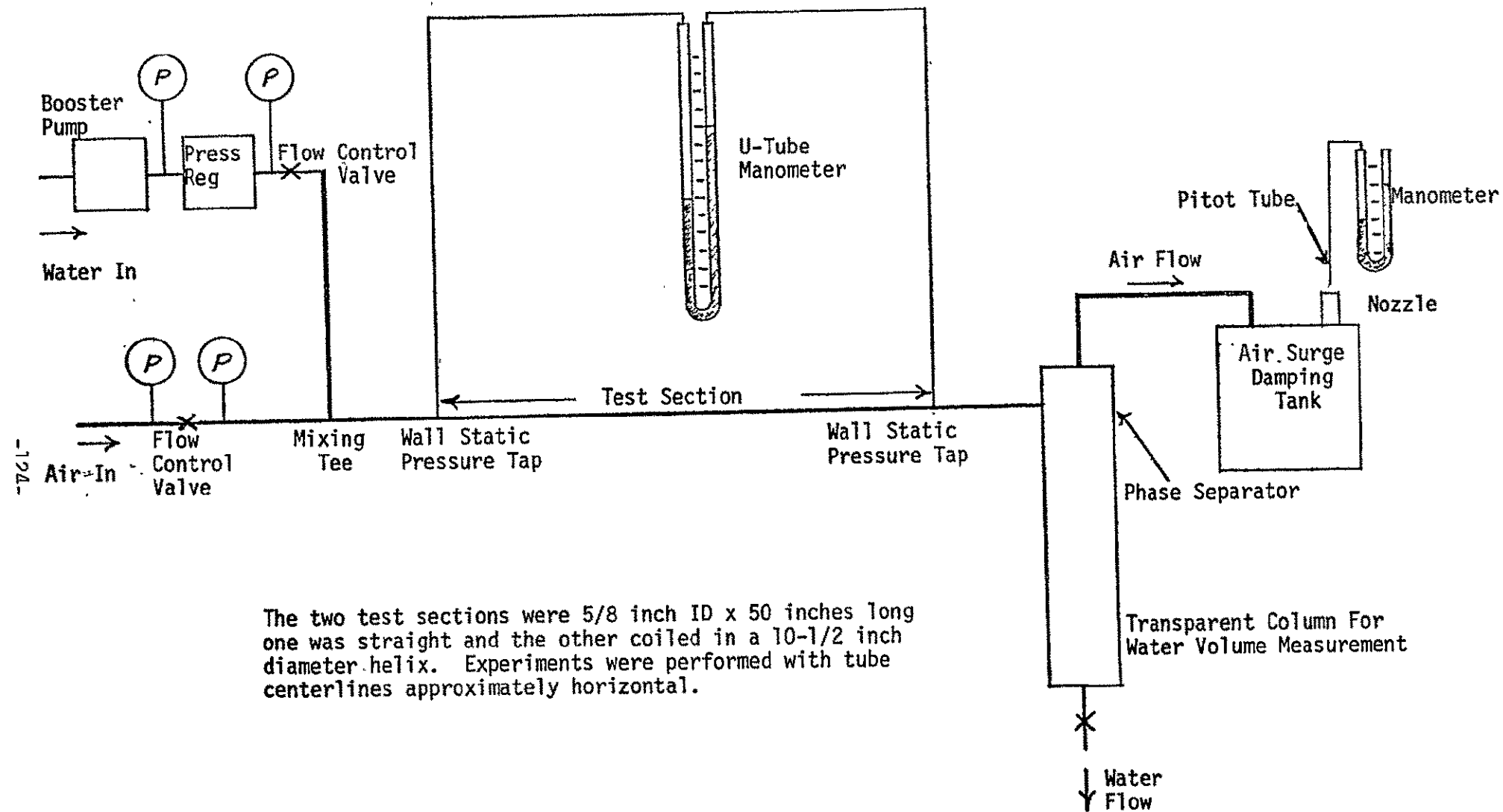


Figure 1

Schematic Diagram of Two Phase Flow Pressure Drop Apparatus

were used in series. This arrangement provided a steady pressure to the metering valve. The water flow was measured by accumulation of a known volume in a known time. To make this measurement, the outlet water valve was closed and the rate of rise of the water in a transparent column of known inside diameter was measured with a stop watch.

Test section pressure drop was measured with a water filled U-tube manometer. Fluctuations in this reading were in some cases as much as 20% of the mean reading. The measurements reported were determined by using the average value of the high and low extremes.

The variations in test section pressure because of the flow pulsations might under some circumstances cause water and air flow variations into the apparatus. However, the actual test section pressures were lower than 1 psig, and both the air line pressure (125 psig) and water line pressure (35 psig regulated) were high enough so that variations in the test section pressure would not significantly affect the flows.

The experiments were performed with constant water flow, varying the air flow to obtain the various mass flow rate ratios reported. The water flow chosen is the maximum expected for the spacecraft application which is near 45 cc/sec.

Results of these experiments are shown in Table II. A discussion of these data is presented in the next section.

TABLE II
STRAIGHT TUBE

Two Phase Air-Water Flow Test, $L/D = 80$, $D = 5/8"$

Run No.	Flow Identification	Air ΔP_a in H_2O	Air \dot{Q}_a ft^3/min	Water \dot{Q}_l cc/sec	Pres. Drop ΔP_{TP} in H_2O
1	SF*	.40	5.42		1/2
2	TF*	"	"	44.4	8.
3	SF	.60	--		11/16
4	SF	1.00	7.66		1-3/8
5	TF	"	"	44.4	13.
6	SF	1.00	"		1-7/16
7	SF	1.70	9.99		2-1/4
8	TF	"	"	44.4	18.
9	SF	1.70	"		2-1/4
10	SF	2.60	12.34	44.4	3-7/16
11	TF	"	"		23-1/2
12	SF	2.60	"		3-7/16

* SF refers to single phase air flow and TF refers to two phase (air-water) flow.

TABLE II (Continued)

HELICAL TUBE

Two Phase Air-Water Flow Test, $L/D = 80$, $D = 5/8"$

Run No.	Flow Identi- fication	Air		Water \dot{Q}_l cc/sec	Pres. Drop ΔP_{TP} in H_2O
		ΔP_a in H_2O	\dot{Q}_a ft^3/min		
1	SF	.4	4.85		15/16
2	TF	"	"	44.4	8-1/2
3	SF	.4	"		15/16
4	SF	1.0	7.66		2-1/16
5	TF	"	"	44.4	14-1/2
6	SF	1.0	"		2-1/16
7	SF	1.7	9.99		3-1/4
8	TF	"	"	44.4	19
9	SF	1.7	"		3-1/4
10	SF	2.6	12.34		4.2
11	TF		"	44.4	24.
12	SF	2.6	"		4.2

C. Comparison of Predicted and Measured Pressure Drop Characteristics

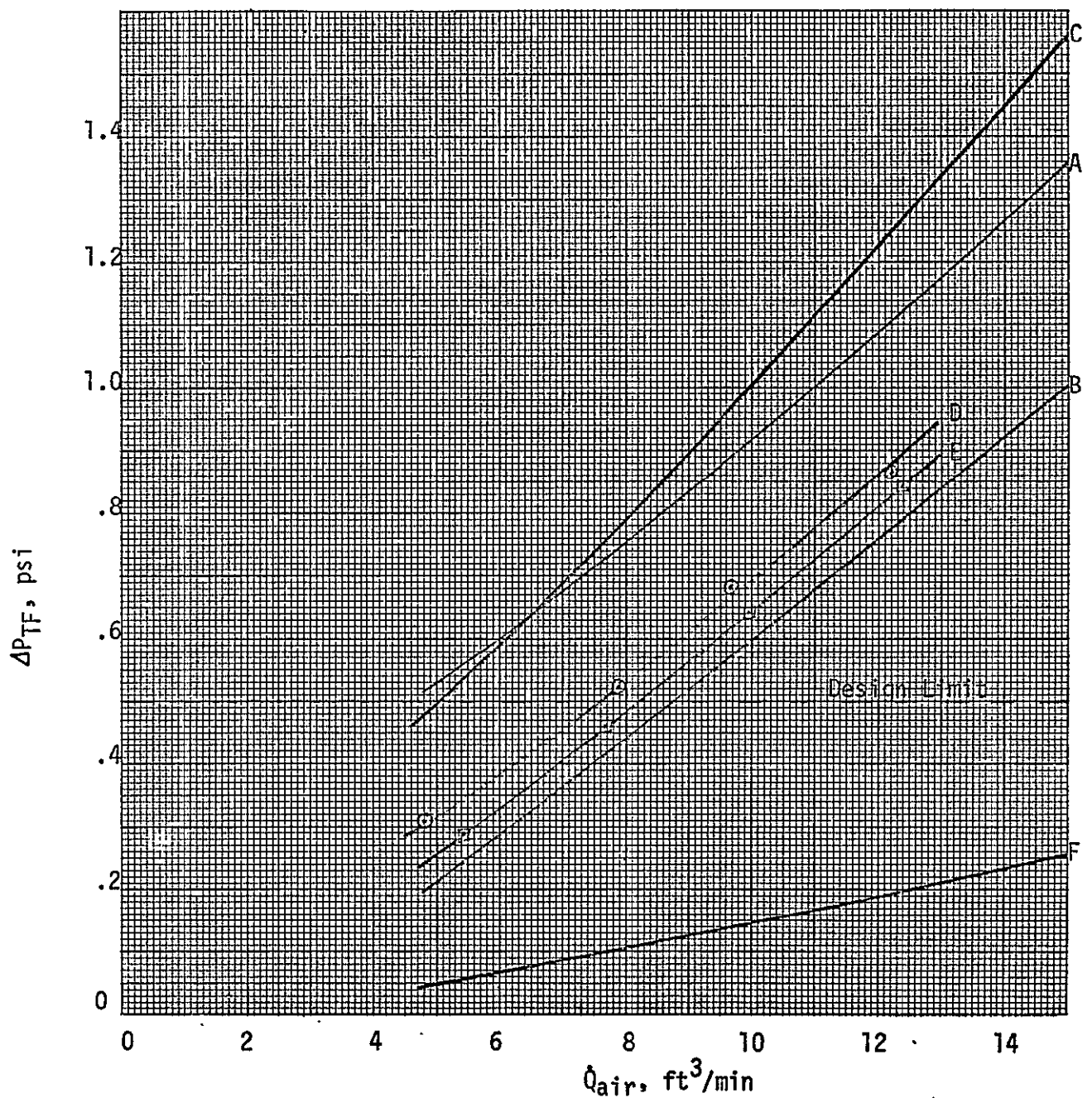
The predicted and measured pressure drop results are shown in Figure 2. Note that the experimental values (for both linear and helical flow) fall reasonably close to the values for the separated flow model (for the case of a rough air-liquid interface).

The slug flow and Martinelli mixed flow predictions fall above the measured values, as expected. This was the case because wetted wall separated flow distributions were observed in the laboratory tests.

Figure 2. Comparison of Two Phase (Air-Water) Flow Pressure Drop Data with Model Predictions.

(5/8" ID Tube - 50" Long, 44.4 cc/sec Water Flow)

- A - Slug Flow Prediction
- B - Divided Flow Prediction ($\zeta = 0.15$, $\zeta_p = 0.03$)
- C - Martinelli Mixed Flow Prediction
- D - Test Data, Helical Flow Tube, 10.5" Dia.
- E - Test Data, Straight Tube
- F - Divided Flow Prediction ($\zeta/\zeta_p = .03/.03$)



III ELECTRONICS PACKAGE CHARACTERISTICS

The electronics package provides the functions of flowmeter operating power supply, signal conditioning and display, control and switching, standby temperature stabilization, and power supply for the various electronic circuits. Table III describes some of these functions in more detail.

Some of the electronics package functions are affected by the two principal changes from past work made for the present program. The changes are: increased flowmeter size required to accommodate much larger air flows and lower pressure drops; and a change in available spacecraft power from 28 volts DC to 115 v, 400 Hz AC. The following paragraphs describe the manner in which each of the electronics package functions is changed by the new requirements.

A. Flowmeter Power

This function is affected by both new requirements. The new flow tube is expected to have the same sensitivity as the smaller one utilized in preceding programs so that a power input of approximately 25 watts will probably be adequate, as before. However, the electrical resistance of the new flow tube is expected to be somewhat lower than formerly, possibly by as much as a factor of two. This comes about because the 0.003 inch tube wall thickness

TABLE III
ELECTRONICS ASSEMBLY FUNCTIONS

1. Flowmeter Power. This function is to supply approximately 30 watts of low voltage AC power to the flowmeter tube during actual flow metering.
2. Flowmeter Processing. This function is to invert, integrate, adjust scale factor, and display integrated flow signal from the flowmeter tube. Total power required for these operations, which are all performed by solid state electronics circuits, depends on specific components chosen. The power required by the breadboard apparatus was less than seven watts in operation, and five watts standby, using components not specifically chosen for power conservation.
3. Control and Switching. One of these functions is to sense the inception of liquid flow; energize the flowmeter power supply and start the integrator; then terminate those functions at the cessation of flow. Another function is to protect the flow tube against over temperature conditions, should other equipment malfunction.
4. Flowmeter Guard Heater Control. The flowmeter guard heater maintains the flowmeter tube and its surrounding thermal insulation at a temperature close to the temperature of the liquid flow to minimize

TABLE III (Continued)
ELECTRONICS ASSEMBLY FUNCTIONS

starting transients at flow inception. This circuit and heater required seven watts in the breadboard apparatus.

5. Electronics Power Supply. These functions are to provide suitable electrical power for the various electronic circuits.

utilized formerly may not be stiff enough for the larger instrument. If the resistance of the tube must indeed be lower, then the current supplied for heating the tube will be larger, leading to heavier electrical conductors and a different transformer output voltage.

The flowmeter power supply will be completely changed by the new spacecraft power specification. Formerly, the power supply utilized a 28 volt DC to 27 volt 800 Hz regulated converter and a specially built 800 Hz step-down transformer to supply the 3 volt (approximately) power to the tube. The converter is no longer required. Instead, a 400 Hz AC regulator (possibly combined with a 400 Hz step-down transformer) will be necessary. Voltage stabilization to 1 per cent against line variations is adequate for power supply to the flow tube. The regulator, whatever its nature, need not stabilize against load variations, since the load is a fixed resistance. A saturated magnetic circuit regulator, similar to those commonly used for regulation of 60 Hz power could possibly be combined with the step-down transformer for this application.

B. Flowmeter Signal Processing

The signal conditioning, integration, and output display functions will be unchanged by the new requirements. The sensitivity of the larger flow tube should not be significantly different from that of the smaller instruments constructed for the preceding program.

C. Control and Switching

The control and switching functions will not be significantly changed by the new requirements.

D. Flowmeter Guard Heating

The guard heater power requirement is expected to increase somewhat for the larger tube. The power required to maintain the flowmeter tube and insulation at a particular temperature is principally a function of the surface area of the assembly, and it appears from initial studies that the area will be approximately three times larger than the former arrangement. The rather large standby power can be reduced somewhat by the use of lower conductivity, thicker thermal insulation covering the guard heater. Until actual space requirements and geometry are established, this power requirement cannot be exactly determined.

E. Electronics Power Supply

Several 28 volts DC to regulated DC converted power supplies were formerly used to energize the electronic circuits. The new power source of 115 volt 400 Hz AC is within the acceptable input range of a wide variety of conventional AC to DC power supplies. Therefore, this change greatly simplifies the choice of power supplies for the electronics modules. It should be possible to provide tighter regulation with smaller, lighter components on the forthcoming equipment.

IV. SYSTEM COMPONENT DIMENSIONS, WEIGHTS AND POWER REQUIREMENTS

Preliminary information on system component dimensions, weights and power requirements are summarized in Table IV.

TABLE IV

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	3 x 3 x 50 or 8 x 12 x 12	3	Tube Heater: 10-30 Environmental Heater: 15
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module*	8 x 8 x 2	2	4

* Includes signal conditioning and display, switching circuits, power supplies, and environmental heater control.

TABLE IV-a

12" water Δp ; 45 cc/sec urine; 8 cfm air; 5/8" I.D. x 50" tube

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	3 x 3 x 50 or 8 x 12 x 12	3	Tube Heater: 10-30 Environmental Heater: 15
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module*	8 x 8 x 2	2	4

TABLE IV-b

6" water Δp ; 45 cc/sec urine; 5 cfm air; 5/8" I.D. x 50" tube

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	3 x 3 x 50 or 8 x 12 x 12	3	Tube Heater: 10-30 Environmental Heater: 15
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module*	8 x 8 x 2	2	4

TABLE IV-c

12" water Δp ; 25 cc/sec urine; ~9 cfm air, 5/8" I.D. x 50" tube

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	3 x 3 x 50 or 8 x 12 x 12	3	Tube Heater: 10-30 Environmental Heater: 15
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module*	8 x 8 x 2	2	4

TABLE IV-d

6" water Δp / 25 cc/sec urine; ~5.5 cfm air; 5/8" I.D. x 50" tube

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	3 x 3 x 50 or 8 x 12 x 12	3	Tube Heater: 10-30 Environmental Heater: 15
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module*	8 x 8 x 2	2	4

TABLE IV-e

12" water Δp ; 25 cc/sec urine; 1 cfm air; 0.25" I.D. x 20" tube

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	2.5" x 2.5" x 20" ~ 0.6 or 4 x 7 x 7		Tube Heater: 30 Environmental Heater: 5
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module ^y	3 x 8 x 2	2	4

TABLE IV-f

6" water Δp ; 25 cc/sec urine; ~ 0.6 cfm air; 0.25" I.D. x 20" tube

Component	Dimensions Inches	Weight Lbs	Power Requirement Watts
Flow Sensor	2.5" x 2.5" x 20" or 4 x 7 x 7	~ 0.6	Tube Heater: 30 Environmental Heater: 5
Flow Sensor Operating Power Supply	3 x 3 x 3	3	3
Electronics Module*	8 x 8 x 2	2	4

V. OTHER POSSIBLE DESIGN MODIFICATIONS

The size of the flow sensor could be reduced if the extreme urine flow rate of 45 cc/sec were reduced. This could be done by locating a "flow storage component" at the entrance of the urine receptacle. For example, a series of screens which would temporarily store and slow-up the urine flow could be added (such an arrangement has already been given some preliminary checks).

A component of this type would have an additional advantage; namely, it would prevent an accidental blockage of the tube at the bottom of the urine receptacle by a foreign object (thereby causing flow tube pressure damage).

Another design alternative would be to increase the air blower characteristics so that higher pressure drops could be allowed for the flow sensor; then sizes and weights could again be reduced.

NOMENCLATURE

Symbols

$\frac{\Delta P}{\Delta L}$	frictional pressure gradient
F	function
\dot{Q}	volumetric flow rate
L	flow tube length
D	inside diameter of flow tube
μ	absolute viscosity
ρ	density
\dot{W}	mass flow rate
r	radial position
ζ	Weisbach friction factor for gaseous core
ζ_p	Weisbach friction factor for a smooth pipe
y	volume fraction of a component

Subscripts

a	air
TPF	two phase
g	gas phase
l	liquid phase
o	tube wall
i	gas-liquid interface



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